MODULA AND THE DESIGN OF A MESSAGE SWITCHING COMMUNICATIONS SYSTEM

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TR 78-329

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1979**	2. REPORT TYPE	3. DATES COVERED **00-00-1979 to 00-00-1979**
4. TITLE AND SUBTITLE **Modula and the Design of a Message Switching Communications System**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Cornell University,Ithaca,NY,14853**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**141**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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This work was supported by the Scientific Services Program of Battelle Columbus Laboratories, Durham, and was authorized by the U.S. Army Research Office under Contract DAAG29-76-D-0100.

ABSTRACT

This report describes the functions of a message switching communications system and presents an implementation in terms of the Modula programming language. In particular, the report: (1) describes a representative application of the proposed new Department of Defense high order language; (2) presents a design technique for software specification; (3) develops Modula programs for each of the message switching components; and (4) evaluates the utility of Modula as a language for the design of large parallel systems.

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1.0 Introduction

The unmistakable trend in recent years has been toward the use of high level languages for systems programming. In an effort to improve upon available tools, three new languages have been designed: Concurrent Pascal [1] and Modula [8] were developed to aid in the design and implementation of multiprogramming systems while Euclid [4] is intended for the programming of verifiable, sequential systems. All three borrow heavily from the work of Wirth in the design of Pascal [7]. Although intended primarily for the development of small operating systems, both Concurrent Pascal and Modula are applicable to parallel systems in general. In this paper, the design of one specific example, a message switching communications system, is developed and programmed in Modula. Our purpose is to show both (1) that a communication system can and should be viewed as a special purpose operating system and (2) that a language such as Modula is an ideal tool for its design. Modula was chosen as the target language because it is well documented, provides facilities for accessing machine hardware, and appears to be efficiently implemented [10].

At present, the Department of Defense is involved in a concerted effort to develop a new language (or family of languages) for use in implementing their software systems [2]. A message switching communications system is one example of such an application [5]; and Modula is a language

which meets many of the DoD requirements, specifically in the areas of parallel processing and device control. A message switch consists of a number of switching nodes, each having local subscribers, connected via trunk lines. Its function is to route messages from one subscriber to one or more other subscribers connected to either the same switching node or to another, remote switching node. Each switching node accepts input messages from subscribers or trunks, stores the messages on temporary storage and then forwards complete messages to output destinations (either local subscribers or trunks). This type of communication system is often called a store-and-forward message switching system.

This report presents a detailed design in Modula of the software for a switching node. (Each switching node in a communications network would execute the same software). In particular, the report:

(1) Develops one completely specified, typical application of the proposed Department of Defense language;

(2) Illustrates the use of top down design and presents a descriptive technique for the specification of parallel software systems; and

(3) Evaluates the utility of Modula for the design of large parallel systems such as the one presented.

Overall Modula proved to be a superb tool, although it

did present a few problems (enumerated in Chapter 6). As testimony to its power, the entire design described here was developed in thirty days (including the writing of this report). Much progress has been made since the early days of exclusive assembly language coding - and even if assembly language must still be used (in hopefully few places), we hope that this report provides justification for the use of a high-level language such as Modula as a tool for initial specification and subsequent documentation.

The next chapter gives the specifications of the hardware, user interface, and fuctions of the communication system. Chapter 3 contains a brief summary of Modula, and block diagrams of the communication system components. Before delving into detailed programs of each component, the different message processing phases are described in Chapter 4. Chapter 5 contains program listings and detailed descriptions of each component. Finally, Chapter 6 summarizes the design and evaluates the utility of Modula.

2.0 System Specifications

In this section, the hardware configuration and processing requirements of a typical message switching communication system are specified. The hardware is discussed at this point in order to give a feel for the size and nature of the switching system under consideration. The most important part of the specification of this or any system, however, is defining the formats of input and output message and the functions the system must perform on the messages (see [5] for more detail).

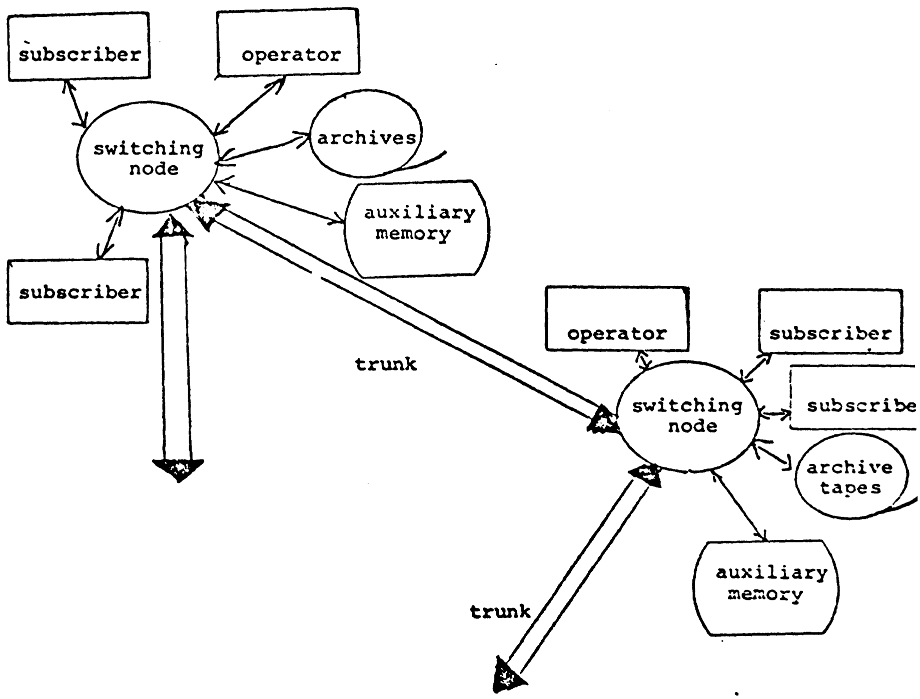
2.1 Hardware

The switching system considered consists of a network of switching nodes each connected to one or more other switching nodes via trunk lines. Connected to each node are a number of local subscribers, one special subscriber called the operator, archive tapes, and auxiliary memory for messages. A representative configuration is shown in Figure 2.1. Typically, a switching node has up to 50 subscribers and from 1 to 3 trunk connections to other nodes. Our design is independent of the number of subscribers and/or trunks, however. We also assume that there are four tape controllers, two for recording input messages and actions on the messages and two for retrieval of data or actions from previously processed messages. For temporary storage of input messages, each node has some auxiliary memory such as a disk.

Subscribers, as well as the operator, use terminals to interface to their local node. Each terminal is assumed to

Figure 2.1

Communication Hardware



subscriber: terminal

operator: terminal

switching node: processor

archives: tapes

auxiliary memory: drum or disk

trunk: communication lines

be a character oriented device, namely it transmits and receives data one character at a time. All terminals are full duplex so that input and output can proceed simultaneously.

Trunks are more complicated. Each consists of a bundle of pairs of sending and receiving lines. Information is transmitted along trunks in 84 character blocks. (The format of trunk messages is described in Section 5 when the trunk program is described.) Control signals are also passed along trunks to synchronize information transmission. We will assume that trunks transmit information at a periodic rate, namely information can be sent or received at fixed intervals rather than asynchronously as with other IO devices. Trunk lines are also assumed to be full duplex.

2.2 System Functions

The basic function of each switching node is to accept input from subscribers and route it to output destinations named in the headers of input messages. There are three phases involved in processing each message: input, switch, and output. In addition, the operator can request special functions, and is notified when exceptions are detected by the switching node.

The input phase involves receiving input from a subscriber or trunk, storing the message on auxiliary memory, and recording the input in an archive tape. Each message contains a header, a body, and an end marker. Once an

entire message has been stored, the switch function is invoked.

In the switch phase, two major actions are taken. First, acknowledgement of receipt of the message is recorded in an action archive and is output on the local operator's terminal. Second, the message header is examined to determine the output destinations. For each destination, the switch module selects an appropriate output line (either a local subscriber or a trunk) and starts the output phase. If a message is sent to more than one destination, each receives a copy. All messages are eventually output to subscribers (unless cancelled).

In the output phase, a message is retrieved from the auxiliary memory and transmitted to each destination. For trunk destinations, the message is sent as a sequence of blocks. For local subscriber destinations, the message is output as a sequence of characters. Each message contains a precedence and classification. At all times, the highest precedence message for each destination is output. If pre-empted, a message is later retransmitted in its entirety. The classification of each message is checked when it is output to a subscriber; it must be no greater than the current classification of the subscriber terminal.

Each switching node has one operator terminal. The operator can send and receive messages like any subscriber. In addition, the operator monitors and controls the activity

of the local node. The operator can request that the switching node perform certain actions (e.g. cancel a message, or retrieve a previously sent message). The operator also is notified of any exceptions or special actions occurring within the switching node (e.g. occurrence of a pre-emption, or need to mount an archive tape).

2.3 IO Interfaces

The main function of the switching node is to process input and output messages. The specific formats of subscriber and trunk IO messages are shown in Figures 2.2 and 2.3, respectively. Input header fields have the following values:

originator code - the number of the line originating the message

destinations - the number and identity of each intended output destination where the identity is a (switching node #, line #) pair

identification - the date and time of input; together with the originator code this uniquely identifies a message

precedence - emergency, routine, or deferred; emergency pre-empts the other two on output

classification - classified or not classified (could use more levels in general)

local sequence number -

subscribers - value N meaning <u>Nth</u> input message

Figure 2.2

Subscriber Interface

Subscriber Input

header:	SOH code originator code destinations identification (date - time) precedence classification local sequence number EOH
body:	sequence of characters
end:	EOM code <u>or</u> cancel sequence, EOM code

Subscriber Output

header:	originator of message identification (date - time) precedence classification local sequence number
body:	sequence of characters
end:	EOM

Figure 2.3

Trunk Interface

Trunk Input

header:	SOH code, SEL code originator destinations identification (date - time) precedence classification list of switching nodes who have processed message ETX code, block parity
body:	STX code, DEL code 80 characters ETB code, block parity
end:	ETX code, block parity (at end of block) <u>or</u> cancel sequence (inside block)

Trunk Output

header:	same as above
body:	same as above
end:	same as above

of the day

trunks - sequence of numbers naming the switching nodes which have processed this message

When a message is output, it basically contains the same information as for input. Two differences exist for subscribers, though. First, the destination no longer needs to be specified. Second, the local sequence number is changed to a count of the number of output messages sent from the switching node to the subscriber. We leave unspecified the actual length and encoding of each header component; the program for the system refers to fields by name.

Operators, as subscribers, can send and receive messages. They have the same format as subscriber messages. In addition, the operator of each node can make certain requests and receives exceptions and other notices. The types of requests and notices are enumerated in Figure 2.4. We assume that requests have a starting code which enables them to be distinguished from normal input messages.

Figure 2.4

Operator Interface

Operator Input

messages: same format as for subscriber input

requests: start of request code
body of request
key
values (up to four)
end of request code

key	value(s)
"status"	types of status to retrieve
"cancel"	message identification
"wait"	line number
"restart"	line number
"alter directory"	line number, new primary and alternate destinations
"alter line status"	line number, new status
"retrieve"	type of retrieval, message identification
"cancel retrieve"	-

Operator Output

messages: same format as for subscriber output

exceptions and notices: pre-emption, orbit, tape mounts, cancellations, actions on messages

3.0 System Structure

The message switch system has been programmed in Modula. This section briefly summarizes Modula and gives block diagrams of the system organization in terms of Modula constructs. Succeeding sections refine the structure into greater levels of detail.

3.1 Summary of Modula

Modula is a new programming language which is intended primarily for programming dedicated software systems. It is based on Pascal [7]. To the sequential language constructs of Pascal it adds two constructs for multiprogramming: processes and modules. It also allows the specification of so called device modules to control a computer's particular peripheral devices.

As an aid to the reader, a short summary of "sequential" Modula data types and control statements appears in Figure 3.1. Figure 3.2 summarizes the process and module constructs which will now be briefly discussed. For detailed information the reader is referred to Modula's defining document [8] and also to the excellent papers describing its use, design and implementation [9,10]. Our purpose here is merely to give the flavor of the language. In order to really understand the programs in Chapter 5, [8] should be consulted.

Processes have the same structure as procedures. Namely, they have parameters, local variables, and a set of statements. They are also activated in the same manner as procedures. The

Figure 3.1

"Sequential" Modula

DATA TYPES

Basic types:	Boolean, char, integer, bits
Constants:	const name = value
Types:	type name = identifier |enumeration| array|record
Enumeration:	(identifier list)
Array:	array range of type
Record:	record fields end
Variables:	var names: type;...

PROGRAM STATEMENTS

```
Assignment:       variable  := expression
Procedure Call:   procedure name (parameters)
If:               if Boolean expression then statement
                     list [elseif Boolean expr then state-
                     ment list]
                     [else statement list] end
Case:             case expression of
                     label1:  begin statement list1 end
                                 :
                     labeln:  begin statement listn end end

While:            while Boolean expression do statements end
Repeat:           repeat statements until Boolean expr;
Loop:             loop statements end
Loop exit:        when Boolean expr do statements exit
```

difference is that when a process is "called," both the process and the caller execute concurrently. In addition to local variables, processes can access global variables and call module operations.

Modules are like blocks in the Algol sense (they contain declarations and statements). The difference is that a module is a fence between the objects it declares and those global to it. The purpose of a module is to make available selectively those objects that represent an intended abstraction while hiding those objects that are considered details of its representation. To specify the fence, a module contains a define list and, optionally, a use list. The define list names those objects exported from the module, namely those objects accessible outside. Procedures, types, constants, signals and read-only variables can be exported. The use list names those global objects imported into the module. If the use list is omitted, all global objects are accessible; if it is present however, only global objects namedin the use list are accessible. Modules also contain statements to initialize local variables.

Two special types of modules play a key role for multiprogramming: interface modules and device modules. Interface modules, which correspond to monitors [3], are modules which provide exclusive access to defined procedures. If one process is executing an interface module procedure, no other process can execute within the interface module. Since it is usually

Figure 3.2

MODULA: Processes and Modules

PROCESSES

```
process SWITCH;
    variables
    begin
      :
    end SWITCH;
```

MODULES

```
module m;
    define names; (*exported types, vars, procedures*)
    use names;  (*imported types, modules, etc.*)
    declarations - variables, types, procedures
    begin
       initialization
    end m;
```

INTERFACE MODULES

modules with exclusive access to defined procedures and with signal variables operated on by wait(sig) and send(sig)

DEVICE MODULES

interface modules with internal device processes which can have doIO statements to delay execution until IO is complete

necessary for cooperating processes to synchronize their actions, interface modules can contain signal variables. Signals are sent by send(signal) and received by wait(signal). When a process waits for a signal it temporarily leaves the module thus relinquishing its exclusive control. A send results in a process switch if another process is waiting for the signal; otherwise it has no effect.

Device modules are special kinds of interface modules. In addition to defined, mutually exclusive procedures, a device module contains device processes. A device process, or driver, interfaces to the IO hardware of a specific device. Therefore, there is one device process for each addressible IO device. To represent time delays due to IO processing, device processes can contain doIO statements. Since device processes are <u>within</u> device modules, when executing they have exclusive access to the module's variables. Device processes relinquish control by waiting or by executing doIO. They regain control when signalled or when IO completes.

A Modula program is a module. Within this outer module all (non-device) processes and other modules are declared and the processes are activated. Process declarations cannot be nested, with the exception of device processes which are declared within device modules. Module declarations can be nested, however.

3.2 System Organization

There are five basic components in the message switch

system. At the center is the SWITCH process which directs activity and keeps track of the status of each message. Message input and output is handled by the trunk and subscriber components. The auxiliary memory group is used for storage of messages. The active-archive is used as a log of the data in messages and the actions taken on messages. Finally, the operator group processes messages (like the subscribers) and handles operator requests and system exceptions. The components and their interconnection are shown in Figure 3.3. The labels on the arcs indicate the types of operations which are performed. The trunk/subscriber groups, SWITCH process, and operator group direct activity. The auxiliary memory and active-archive groups provide services to the other three.

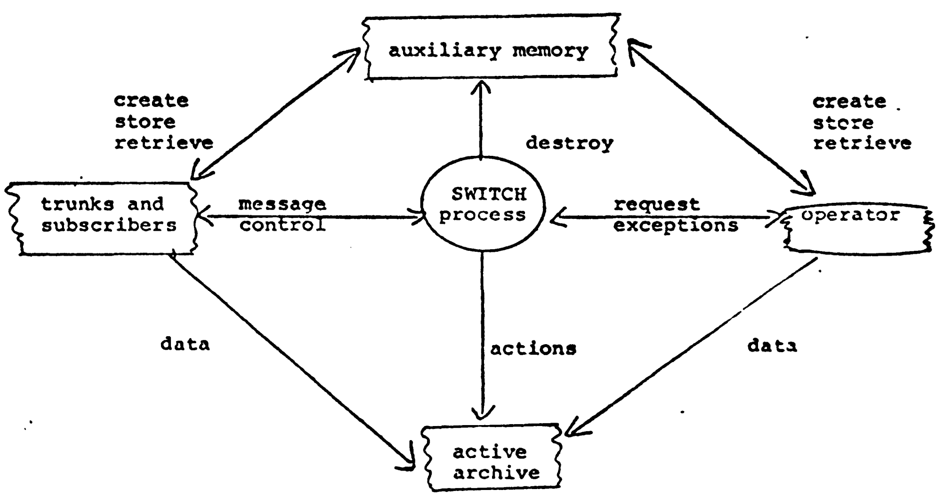
The specific organizations of each component, in terms of Modula units, are shown in Figures 3.4-3.7.* Trunks and subscribers are both organized in the same way; as will be seen in their programs (Chapter 5) they differ only as a result of the hardware difference between terminals and trunk lines. Their organization and interface to the rest of the system make differences transparent, however. Each consists of two controlling processes, one for input and one for output, as well as a device module for performing IO. Controller processes send or receive headers and blocks of data to and

---

*Capital letters are used for the names of the processes and modules; circles denote processes and boxes denote modules.

Figure 3.3

System Components



from the other components. The input control process in both cases reads from the input device and the output control process writes to the device. Within the device module are two IO drivers. Note that there are two control processes and one device module for each terminal or trunk line.

The trunk and subscriber input processes store a copy of each input block on the ACTIVE ARCHIVE. The ACTIVE ARCHIVE is implemented as a device module containing two driver processes, one for data and one for actions. The SWITCH process sends action messages to the ACTIVE ARCHIVE which in turn stores them on an action tape.

The auxiliary memory group has an interesting organization. Each message input to a subscriber or trunk is stored, by blocks, on auxiliary storage in a file created when input started. During output, the message is read back from auxiliary storage and, when output is completed, the storage file is destroyed. The MEMORY interface module provides operations (defined procedures) for create, destroy, read and write. For read and write it uses an internal device module to access auxiliary storage. This module schedules the IO operation which is in turn performed by a driver process.

The operator group also has an interesting organization. The main component is the operator subscriber which is the same as a normal subscriber (i.e. input and output control

Figure 3.4

Trunks and Subscribers

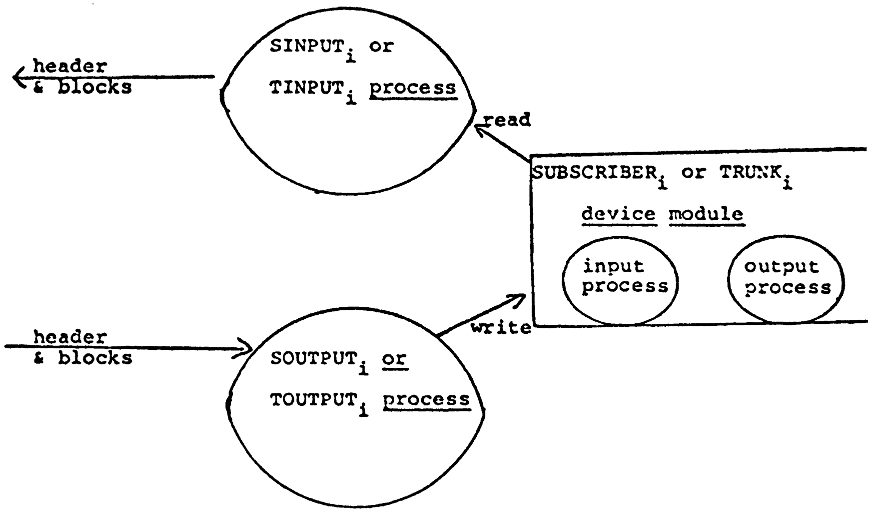


Figure 3.5

Active Archive

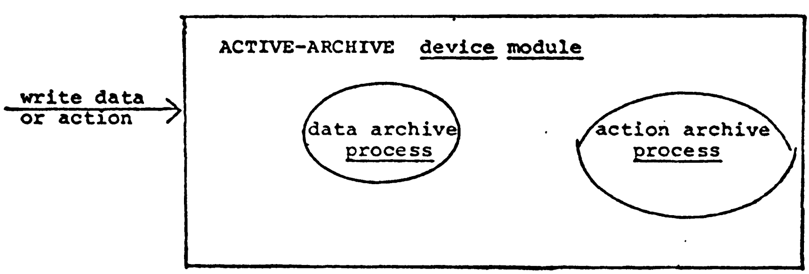


Figure 3.6

Auxiliary Memory

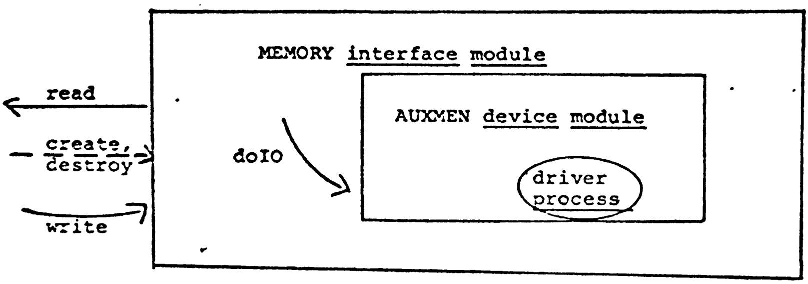
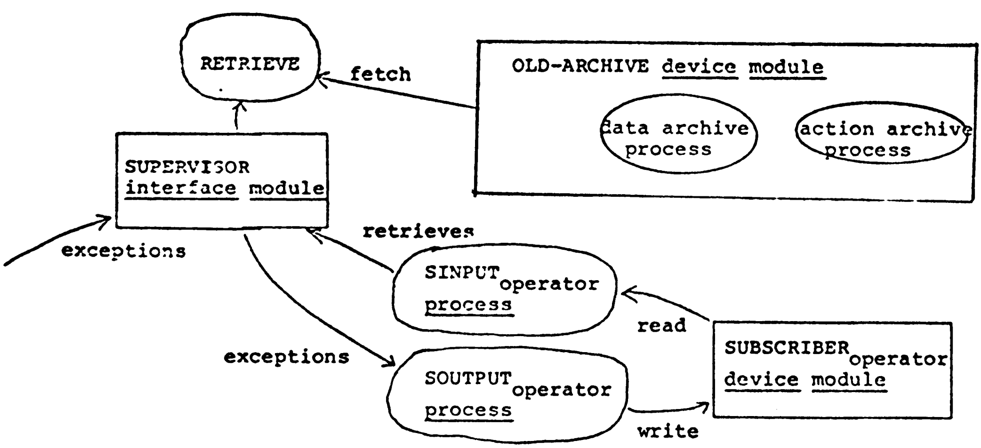


Figure 3.7

Operator



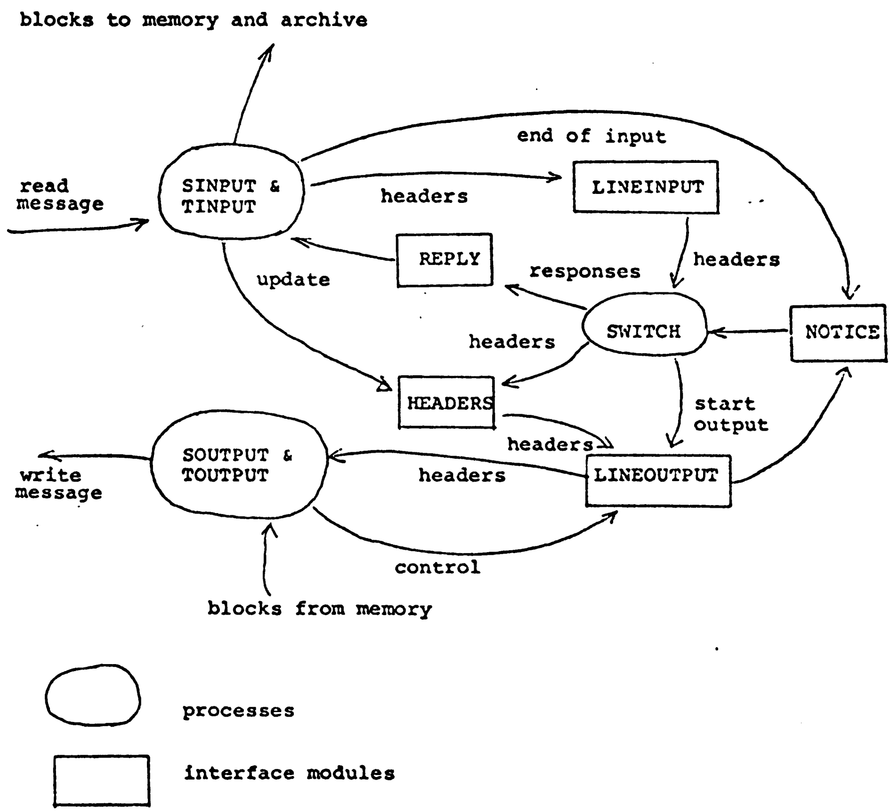
processes and a device module). In addition to handling normal messages, the operator receives exception messages and can request retrieval of past messages. To do so, the SUPERVISOR interface module is used. Exception messages are put into the SUPERVISOR module by the SWITCH process and are handled by the operator's output control process (SOUTPUT). Retrievals are initiated by the operator's input control process (SINPUT) and handled by the RETRIEVE process. The RETRIEVE process reads from the OLD ARCHIVE device module which contains driver processes for reading action and data archive tapes.

Input and output control processes interact directly with the ACTIVE-ARCHIVE and MEMORY interface modules. All message blocks pass between the control processes and MEMORY. Message headers, which contain all of the control information for a message, pass between the IO control processes and the SWITCH process. In addition, IO control processes and SWITCH exchange control signals. Interfacing the control processes to the SWITCH requires a number of interface modules. A diagram of the interface is shown in Figure 3.8. Since SWITCH is a process, it can only wait for one thing at a time. Therefore it receives all requests (e.g. new message, end of output, exception) from a NOTICE interface module. For new messages, it gets the header from LINEINPUT and stores it in HEADERS. At the end of input, it enters output directives for each destination line in LINEOUTPUT. Once

the output is scheduled, LINEOUTPUT retrieves the header from HEADERS and gives it to the appropriate output control process (one of the SOUTPUT or TOUTPUT processes). When output is complete, SWITCH receives a NOTICE, deletes the header from HEADERS and destroys the MEMORY file containing the message. The other interface module in Figure 3.8, REPLY, is used when input or output controllers need to wait for the SWITCH to respond to a notice. The flow of headers and control information between the IO controllers and SWITCH is described in more detail in the next chapter.

Figure 3.8

Trunk/Subscriber - SWITCH Interface



4.0 Process Actions and Control Paths

Before presenting programs for each process and module, in this chapter we summarize the actions of the main processes and describe the paths of messages through the system. The main actions of a switching node are centered in three areas: the input control processes, SWITCH, and the output control processes. Figures 4.1 - 4.3 summarize the functions of these three components in Shaw's flowchart-like notation called path descriptions [6].

For each message, an input process parses the header, groups the body of the message into blocks and finds the end of message code. After a header has been found, a MEMORY file is created and the header is sent to SWITCH via LINEINPUT. Each subsequent block of the message is stored in the MEMORY file and a copy is also stored in the ACTIVE ARCHIVE. When the end of the message is found, either a cancel or end of input NOTICE is sent to SWITCH.

SWITCH receives notices of many kinds (Figure 4.2). For now, three are important: header, end of input, and end of output (done). The others come from the operator (discussed shortly) or indicate exceptions. On receipt of a header NOTICE, SWITCH receives the header itself from LINEINPUT and stores it in HEADERS. SWITCH then logs an action messages on the ACTIVE-ARCHIVE and sends a REPLY to the input process which sent the header. When SWITCH receives an end of input NOTICE, it again logs an action message and then inserts one

Figure 4.1

Input Process Functions

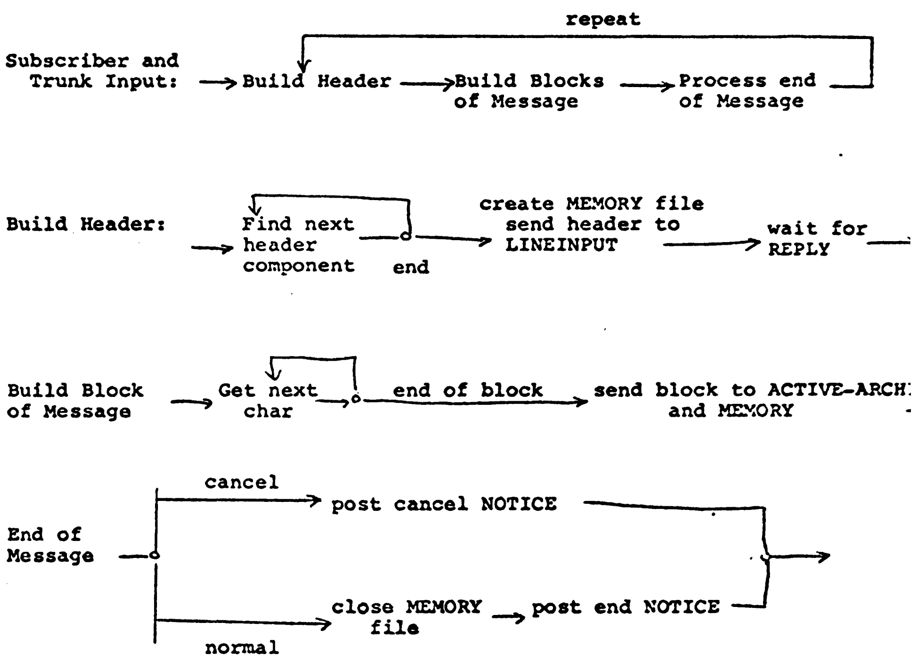


Figure 4.2

SWITCH Functions

```
SWITCH:       ——> receive NOTICE ——┬——> header ——————————┐
                                   ├——> end of input ————┼——>
                                   ├——> done with output ┤
                                   └——> other notices ———┘

header:       ——> receive    ——> enter in  --> put status   ——> send REPLY ——>
                  LINEINPUT      HEADERS       in ARCHIVE

end of input: ——> put status ——> insert in    ——>
                  in ARCHIVE     LINEOUTPUT
                                 for destmations

done with:    ——> put status ——> delete  ——> destroy MEMORY ——>
  output          in ARCHIVE     HEADERS        file

other notices:        ignore for now
```

output directive in LINEOUTPUT for each destination. When output is complete, SWITCH receives a done NOTICE. It again logs an action message, then deletes the header from HEADERS and destroys the MEMORY file containing the message body.

Each output control process (Figure 4.3) gets headers from LINEOUTPUT. On receipt of a header, it outputs the header and then outputs the body of the message by reading blocks from MEMORY and writing them on the output device (via the device module). While one message is being output, another message of higher precedence may be ready for output to the same device. When this happens, LINEOUTPUT sets a pre-emption flag. This flag is periodically examined by the output process and, if set, writing stops and the process receives the new header from LINEOUTPUT.

Figure 4.4 puts these three processes together. It shows the order of the actions taken by each component in processing any message from input through to output. The arrow on each arc indicates the direction of flow of information and synchronization signals.

The other major functions in the system are those of the operator. The operator handles both normal message input and output (in the same way as for subscribers and trunks) and special input requests and output messages. For retrieve, cancel, wait, restart, and alter requests, the operator posts a NOTICE for SWITCH. In the case of alter, the operator passes the new table values to SWITCH via the

Figure 4.3

Output Process Functions

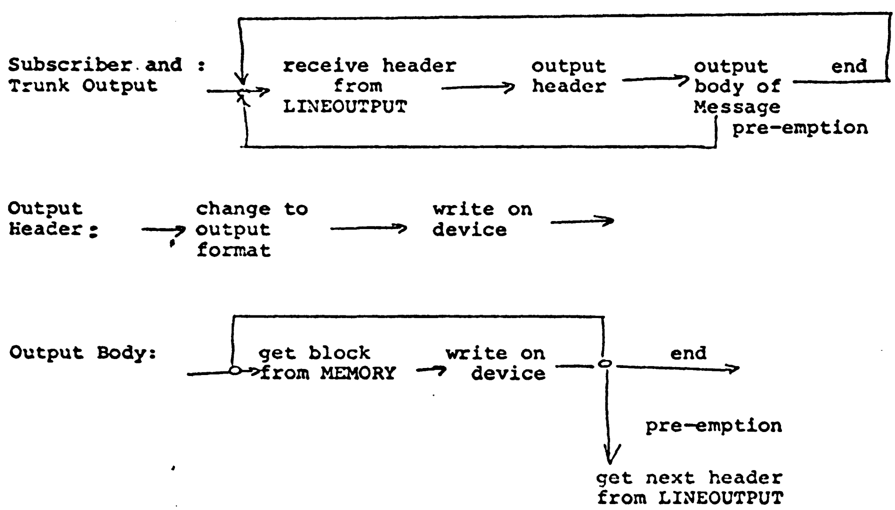
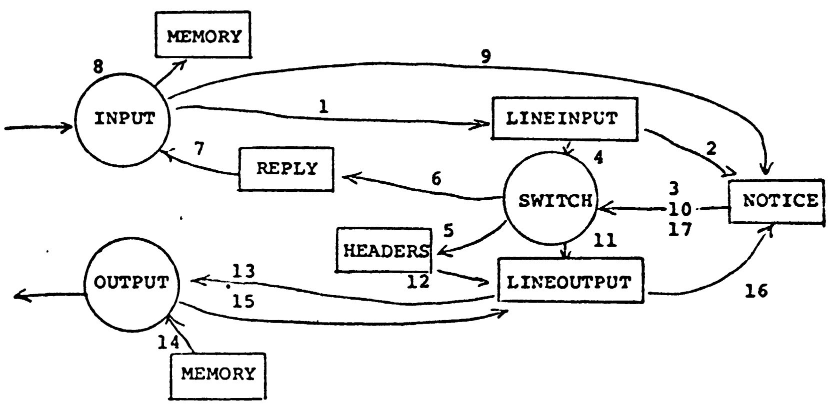


Figure 4.4

IO Control - SWITCH Interface Timing



INPUT PHASE

1 send new header
2 post new msg NOTICE
3 receive NOTICE
4 receive header
5 store header
6 send REPLY
7 receive REPLY
8 store message on MEMORY
9 send end of msg NOTICE
10 receive NOTICE

OUTPUT PHASE

11 insert output msg in LINEOUTPUT
12 retrieve header
13 receive header
14 read message from MEMORY
15 send done with output signal
16 post done NOTICE
17 receive done NOTICE

SUPERVISOR interface module. When SWITCH receives one of these requests (via NOTICE) it takes care of it and sends a response back to the operator. These responses, as well as exceptions and special conditions (e.g. mount a new archive tape), are sent to the operator output process via SUPERVISOR. The control signal telling the operator that a response or other message is waiting comes from LINEOUTPUT in the form of a special header. Output processes get all their work from LINEOUTPUT in the same way that SWITCH gets all its work from NOTICE.

Figure 4.5

Operator Functions

Operator Input: → get next request →
- → retrieve status →
- → cancel →
- → wait/restart →
- → alter tables →
- → retrieve →
- → new tape →

retrieve, cancel, wait/restart: → post NOTICE for SWITCH →

alter tables: → send request to SUPERVISOR → post NOTICE for SWITCH →

retrieve:
- start → send doretrieve to SUPERVISOR →
- cancel → send cancel retrieve to SUPERVISOR →

newtape: → tell archive tape is mounted →

Operator Output: → get operator output notice from LINEOUTPUT → receive output msg from SUPERVISOR → write on terminal

5.0 Program Listings

This chapter contains listings for each of the program components comprising the message switching node. Figure 5.1 gives an outline of the program. Succeeding sections of this chapter discuss each group in detail.

In order to make the listings more readable, three conventions which are not in Modula have been used. First, numeric constants are often denoted by a character string in quotation marks; for example "pre-empt" or "inheader." These could of course be represented in Modula by constant declarations. Upper bounds of arrays are usually just specified as "max"; the appropriate value to substitute is dependent on the actual size of the system.

Second, module procedures are called by specifying both the module name and procedure name. For example, SUBSCRIBER.read calls the read operation of the SUBSCRIBER module. In Modula, only the procedure name is used which requires that each procedure name is unique.

Third, queues have been added as an extension to the usual Modula data types. They are declared as:

```
name: queue maximum size of type
```

and can be operated on by three operations:

```
name.delete(entry)
name.insert(entry)
name.size
```

This shortcut has been employed within interface modules in order to decrease the length of the programs and, hopefully, increase their readability.

Queues as used here can be readily implemented in Modula in a variety of ways. The most obvious was is to use an array

Figure 5.1

Program Outline

```
module MESSAGE-SWITCH;

     global data types - header, block, actionmsg, operator
          request, operator output

     system clock group - TIMER device module, CLOCK process

     MEMORY and ACTIVE ARCHIVE interface modules.

     IO - SWITCH interface modules -
          LINEINPUT, NOTICE, REPLY, HEADERS, LINEOUTPUT,
          SUPERVISOR

     Subscriber groups - SINPUT & SOUTPUT processes SUBSCRIBER
          device module

     Trunk groups - TINPUT & TOUTPUT processes TRUNK device
          module

     SWITCH process

     Operator group - OPINPUT & OPOUTPUT processes
          OPERATOR device module, RETRIEVE process
          OLD-ARCHIVE device module

     begin activate all processes

end MESSAGE-SWITCH
```

and three control variables as follows:

```
name:  queue n of T becomes

name:  array 1 : n of T;
       size, front, rear : integer;
       size := 0; front := 1; rear := 1;
```

The operations insert and delete then respectively add an element of type T at the rear of the array and delete an element from the front. The control variables are adjusted appropriately. The size operation of course just yields the value of size above. The four variables (array plus controls) could also be grouped into a record.

Another implementation is to use a module which defines the type of queue entries and the three operations insert, delete and size. Inside the module, queues are then represented as above by an array and control variables. Although this approach is feasible, a different module must be defined for each type of queue. Modula has no facility for so-called generic or polymorphic types. Since each of the queues used in the message switch system has a unique type the module approach would require a distinct module for each queue.

5.1 Global Data Types

Five types of data are used throughout the system: header, block, actionmsg, operator request, operatoroutput. They are declared in Figure 5.2. Type header contains all of the header and control information for messages. Block is the unit passed to and from MEMORY and the archives. An actionmsg is the type of information stored on the archive's action tapes. Operator request and operatoroutput define the formats of information passed to and from the SUPERVISOR module (which

Figure 5.2

Global Data Types

```
type header = record

          origin: integer; (* line # of sender *)
          outputcount: integer; (* no. of. destinations*)
          dests:  array 1: "max" of integer;
          prec, class: integer; (* precedence, classification*)
          identity: integer; (* date-time-origin*)
          seqcount: integer; (* sequence data*)
          sequence: array 1: "max" of integer;
          size:  integer; (* no. of blocks in msg*)
          filename:  integer  (* MEMORY file*)
          end;

block = array 1: "blocklength" of char; (* msg blocks*)

actionmsg = record (* actions stored on archive*)
            msgid, time, action: integer end;

operatorrequest = record key: integer; (* type of request*)
                  value: array 1:4 of integer end;

operatoroutput = record size: integer; (* no. of chars*)
                 data: array 1: "max" of char end;
```

interfaces SWITCH to the operator).

5.2 System Clock Group

In order to keep track of the time of day and synchronize trunk IO, a TIMER device module and a CLOCK process are employed. The TIMER contains a device process, clock driver, which periodically receives (via doIO) a hardware clock interrupt. It then increments the time of day and sends a tick signal. The CLOCK process receives the tick signal and, for each TRUNK process waiting for IO synchronization (see Section 5.6), sends a trunk tick. If the period of the trunk tick is a multiple of the period of the hardware clock, the CLOCK process would accumulate clock ticks until the period has passed and then send a trunk tick. The TIMER and CLOCK are shown in Figure 5.3. The trunk and hardware clock periods are assumed to be equal for now. For an interesting discussion of hardware clock and Modula, the reader is referred to page 81 of [10].

5.3 MEMORY Interface Module

The MEMORY module provides an interface between IO control processes (subscribers and trunks) and auxiliary memory. It is organized as shown in Figure 3.6. A program outline of the module is shown in Figure 5.4 and the program is given in Figure 5.5. The MEMORY module manages free space on the auxiliary storage device and defines operations

Figure 5.3

System Clock Group

```
var trunktick : signal;  (*synchronization for trunk IO*)
device module TIMER;
     define time of day, tick;
     var    time of day : integer; (*number of hardware clock
                               interrupts since system initialization
            tick : signal; (*signal for each hardware clock interrup
     process  clockdriver;
          begin loop doIO; (*wait for interrupt*)
               inc(time of day); send (tick)
                    end
          end clockdriver;
     begin time of day := 0; clockdriver
     end TIMER;

process CLOCK;
     use tick;
     begin loop wait (tick);
          while awaited (trunktick) do send (trunktick) end
          end
     end CLOCK;
```

Figure 5.4

Outline of MEMORY

```
interface module MEMORY;

     variables - directory, free space, waiting processes

     utility procedures - manage free space

     defined operations - create, write, endwrite, read, destroy

     device module AUXMEM;

          variables - sector buffer, scheduling

          utility procedures - IO scheduling

          defined operation - IO

          process driver
               code to perform IO
               end driver;

          begin initialize AUXMEM

          end AUXMEM

     begin initialize MEMORY

     end MEMORY;
```

for managing files and performing IO. Five operations are defined: create, write, endwrite, read, and destroy.

Create is called by input control processes. Its function is to allocate storage space for the file and assign an internal name. The estimated size of the file is specified as a parameter. If not enough space is currently available, the user or sending trunk is notified and the input controller waits. Once adequate space has been released (via destroy or endwrite) the creating process continues.

Once created, a file is filled by calling write, specifying the filename and data block. Write is in general called many times. The write operation treats the file as a sequential file and writes into the next allocated external block. Since auxiliary memory sectors are assumed to be larger than data blocks, on most writes the old sector must be read, updated, and then rewritten. Sectors of external memory are allocated on demand and are linked together. The links are stored in the directory of the file.

A file is "closed" by calling endwrite. The purpose of endwrite is to tell the file system (i.e. MEMORY) how much space was actually used. On creation, an estimate of the maximum required space is specified, and MEMORY commits that much space. Endwrite enables MEMORY to take back any unused space and make it available for other files.

File reading is performed by input control processes in subscribers and trunks. A call to the read operation identifies the file, block number, and buffer to use.

MEMORY maps the file name and block number into a sector address and calls AUXMEM to perform the IO. The block number must be specified on read because many processes may simultaneously be reading different blocks from the same file (messages may have multiple destinations).

Once all processing on a file is completed, SWITCH calls destroy. Destroy frees the space occupied by the file and, if necessary, tries to awaken processes waiting to execute create. Waiting processes are awakened in the order in which they blocked regardless of how much space they need.

AUXMEM is a device module which schedules and performs read and write operations on auxiliary memory (if necessary). IO is actually performed by the driver process. The read and write operations in MEMORY give IO requests to AUXMEM by calling its IO operation. IO requests a turn, synchronizes with the driver process and then releases its turn. Request turn and releaseturn are scheduling procedures. As defined in Figure 5.5, request turn and release turn use a first-come, first-served strategy. Other scheduling strategies, such as the elevator algorithm in [ ], can be readily implemented merely by changing the bodies of the scheduling procedures.

The driver process synchronizes with the IO procedure via startio and iodone signals. Notice that many processes could be in IO at once, waiting to be scheduled (by request turn). Only one process at a time can be waiting for iodone

however.

The code for MEMORY, which contains AUXMEM as a submodule, is shown in Figure 5.5. AUXMEM is contained within MEMORY because it is part of the representation of MEMORY and hence is not directly accessible to control processes. MEMORY provides the abstraction of a file system. The abstraction, namely the file operations, are all that MEMORY's users see.

Figure 5.5

Auxiliary Memory Interface

```
interface module MEMORY;

    define  create, destroy, read, write, endwrite;

    use  NOTICE;

    const  sectorsize = n1; (* no. of blocks in sector*)
           memorysize = n2; (* no. of sectors in memory*)
           max # files = n3; (* maximum number of files*)

    type file = record        (* format of file descriptor*)
           name, claim, used, curblock: integer;
           sectors: array 1: maxfilesize of integer
           end;

    var  directory:  array 1:  max # files of file;
         free directories:  queue max # files of integer;
                            (* empty directories*)
         free space: queue memorysize of integer;
         committed:  integer; (* no. of sectors claimed or
                        actually used *)
         waitingdata:  queue n of integer;  (* queue of
                        requested sizes for processes waiting
                        to create *)
          spacenowavail  :  signal; (* for processes waiting
                              to do create *)
         i:  integer; (* loop counter in initialization *)


procedure  spaceavail  (size: integer): Boolean; (* size is
                                    estimated no. of sectors *)

    begin
       if committed + nsecs <= memory size
         then  spaceavail  = true
         else  spaceavail  = false
         end

    end spaceavail;
```

Figure 5.5 (Continued)
Auxiliary Memory Interface

```
procedure  request (sector, filename: integer);

    begin
      freespace.remove(sector)
      with directory (filename) do
           inc(used); sectors(used):=sector end;

    end request


procedure  release (filename: integer);

    var  i: integer;

    begin i:=1; with directory(filename) do
          repeat freespace.insert (sectors(i))
                 inc(i)
          until i> used
          committed:=committed-used end

    end release;


procedure  create (msgid, size : integer; var filename : integer);

      var   nsecs : integer; (*estimated no. of sectors*)

      begin nsecs := size div sectorsize;
            if size mod sectorsize > 0 then inc(nsecs) end;

      if    freedirectories.size = 0 then
            (*do something about the exception - e.g. send
              NOTICE to SWITCH or wait for file to be destroyed*)
            end

      freedirectories.remove(filename);

      with directory (filename) do
            extname := msgid; claim := nsecs; used := 0;
            curblock := 0

            end
```

Figure 5.5 (Continued)
Auxiliary Memory Interface

```
    if not spaceavail(nsecs)

        then
            NOTICE.post("stop",line#)   (*tell user to stop input*)
            waitingdata.insert(nsecs);
            wait(spacenowavail);
            NOTICE.post("restart", line#)   (*line # can be computed
                                             from msgid which contains
                                             the origin of the
                                             message*)
        end

    committed := committed + nsecs;

    end create;


procedure write(filename : integer; var buffer : block);

    var S : integer;

    begin

        with directory(filename) do
            if curblock=0 then (*allocate new sector*)
                freespace.remove(s);
                inc(used);
                sectors(used) := S;
                AUXMEM.IO("write", buffer, S,0);

            else
                AUXMEM.IO("read/write", buffer, sectors(used),
                          curblock);

            end
            inc(curblock);
            if curblock > sectorsize then curblock := 0 end

        end

    end write;
```

Figure 5.5 (Continued)
Auxiliary Memory Interface

```
procedure endwrite(filename : integer);

    var allocate : Boolean;

    begin

        with directory(filename)do
            committed := committed-claim+used  (*update actual
                                                 amount of committed
                                                 storage*)
            end
        (* see if waiting processes can now proceed*)

        allocate := true;

        while allocate do

            if  waitingdata.front <=memorysize-committed

                then waiting data.remove; signal(spacenowavail)

                else  allocate := false end

        end

    end endwrite;



procedure read(filename,blnO : integer; var buffer : block);

    var S,O : integer;

    begin

        with directory(filename)do
            S := blno div sectorsize; (*sector number*)
            O := blno mod sectorsize: (*offset in sector*)
            AUXMEM.IO("read", buffer, sectors(S),O)

        end

    end read;
```

Figure 5.5 (Continued)
Auxiliary Memory Interface

```
procedure destroy(filename : integer)

    var allocate : Boolean;

    begin

        (*release file space*)
        release(filename);
        (* delete filename from directory*)
        freedirectories.insert(filename)
        (*awaken processes waiting to create files*)
        allocate := true;

        while  allocate do

            if waitingdata.front <= memorysize-committed
                then  waitingdata.remove; send(spacenowavail)
                else allocate := false end

        end

    end destroy;


device module AUXMEM;

    define IO;

    use sectorsize

    var  (*communication with driver process*)
        op,sec : integer; (*operation, sector*)
        IO avail : Boolean; (*operation ready for driver*)
        startiO, iOdone : signal; (*driver synchronization*)

            (*IO buffer for driver*)
        sectorbuffer : array 1 : sectorsize of block;

            (*variables for IO scheduling*)
            (*just use FCFS for now- could use elevator algorithm
                                        of Hoare*)
        turn : signal;
        deviceallocated : Boolean;
```

Figure 5.5 (Continued)
Auxiliary Memory Interface

```
procedure  requestturn(sector :  integer)

    begin
         (*schedule  IO operations in an order which controls
         latency and rotation delays*)

         (*for now, will just use FCFS*)

         if deviceallocated then wait(turn);
         deviceallocated := true;

    end requestturn;



procedure releaseturn(sector : integer)

    begin

         (*select next process to get its turn doing IO*)

         deviceallocated := false;
         send(turn)

    end releasoturn;



procedure IO(operation : integer; var buffer : block; sector,
             offset : integer);

    begin
         requestturn(sector); (*wait to be scheduled*)

         case operation of

"read" : begin op := "read"; sec := sector;
         IOavail := true; send(startiO);
         wait(iOdone);
         buffer := sectorbuffer[offset]

    end;
```

Figure 5.5 (Continued)
Auxiliary Memory Interface

```
"write" : begin  op := "write"; sec := sector;
                 sectorbuffer[offset] := buffer;
                 IOavail := true; send(startiO)
                 wait(iOdone)

          end

"read/write" : begin
                 op := "read"; sec := sector; (*read sector*)
                 IOavail := true; send(startiO);
                 wait(iOdone);
                 sectorbuffer[offset] := buffer; (*update sector*)
                 op := "write"; sec := sector; (*write it back*)
                 IOavail := false; send(startiO);
                 wait(iOdone)

        end

        end; (*of case*)

        releaseturn(sector) (*let next process be scheduled*)

    end doIO;


process driver;

    begin

    loop
        if not IOavail then wait(startio);

        format operation on sector into or out of sector buffer;
        doIO;

        IOavail := false; send(iodone)

    end

    end driver;
```

Figure 5.5 (Continued)

Auxiliary Memory Interface

```
begin (*initialize AUXMEM*)
        IOavail := false; deviceallocated := false;
        driver
end AUXMEM;


(*initialization of MEMORY*)
    begin
        (*initialize all directories to free*)
        i := 1
        repeat freedirectories.insert(i)
               inc(i)
        until i > max#files;
        (*initialize free space*)
        i := 1
        repeat freespace.insert(i)
               inc(i)
        until i > memorysize
end MEMORY;
```

5.4 ACTIVE-ARCHIVE Module

The ACTIVE-ARCHIVE module is organized as shown in Figure 3.5. It provides an interface to the archive tapes. All data blocks are stored on a data tape; all actions taken on a message are stored on the action tape. To cause data and action messages to be writen, the ACTIVE-ARCHIVE provides two operations, data and action (there are actually three - resume is discussed below). Both operations store their parameters (a block or actionmessage respectively) in a buffer. When the buffer is full, it is output by either the data archive or tape archive device process. For efficiency, namely to reduce the space taken up by inter-record gaps, messages are blocked before transmission to the tape. Neither blocks or action messages are ordered by the sender; data or action messages from different input devices are in general interleaved. Each has an identifier field however, in case it ever needs to be retrieved (see Section 5.9).

The ACTIVE-ARCHIVE program is listed in Figure 5.6. Its logic is straightforward. The one exception occurs when a tape has been filled. In this case, SWITCH is notified (via NOTICE). SWITCH will subsequently tell the operator to mount a new tape. Once it is mounted, the operator's input process calls resume which allows writing to continue.

Figure 5.6

ACTIVE ARCHIVE

```
device module ACTIVE-ARCHIVE;

    define  action,data,resume;

    use  NOTICE, block,actionmsg;

    constant  actiontapesize = m1;  (*# of records  on action tape*)
        datatapesize = m2;  (*# of records on data tape*)
        actionrecordsize = n1;  (*# of msgs in action record*)
        datarecordsize = n2;  (*# blocks in data record*)


    var  arno, drnO, abnO , dbnO : integer; (*current count of acti
                                          data records and blocks*)
        (*declare blocking buffers for tapes*)

        actionbuffer : array 1 : actionrecordsize of actionmsg;
        databuffer :  array 1 : datarecordsize of record id :inte
                               info : block end;
        outputaction,actiondone,outputdata,datadone,
                               tapemounted : signal; (*driver
                                                    synchronizatio
        actionavail,dataavail : Boolean;


procedure  action (act : actionmsg);

    begin  (*write actionmsg on action tape*)
        inc(abnO);  (*store action message*)
        actionbuffer(abnO) := act;

        if abnO = actionrecordsize
            then  actionavail := true;  (*output action buffer*)
                  signal(outputaction);
                  wait(actiondone);
                  abnO := 0;
                  inc(arnO) end;
```

Figure 5.6 (Continued)
ACTIVE ARCHIVE

```
    if arnO = actiontapesize (*end of tape*)
        then  (*tell operator to mount new tape*)
              NOTICE.post ("exception", "mountactiontape");
              wait (tapemounted);
              arnO := 0  end

end action;


procedure data (insgid : integer; bl : block); (*write  msgid and
                                                  block on data tape*)

begin
    inc(dbnO);     (*store block*)
    databuffer(dbnO).id :=  msgid;
    databuffer(dbnO). info := bl;

    if dbno = datarecordsize
        then (*output data record buffer*)
             dataavail := true;
             signal (outputdata);
             wait (datadone);
             dbno := 0;
             inc(drnO)  end;

if drno = datatapesize  (*end of tape*)
    then (*tell operator to mount new tape*)
         NOTICE.post ("exception", "mountdatatape");
         wait (tapemounted);
         drnO := 0  end

end data;
```

Figure 5.6 (Continued)
ACTIVE ARCHIVE

```
procedure  resume;
    (*called by OPERATOR INPUT process when operator says that
      a new tape has been mounted*)

    begin
        signal (tapemounted)

    end resume;


process  dataarchive;

    begin loop
        if not dataavail then wait(outputdata) end;

        initiate output of contents of data buffer;
        doIO;
        dataavail := false;
        signal (datadone)
        end

    end dataarchive;


process action archive;

    begin loop
        if not actionavail then wait (outputaction ) end;
        initiate output of contents of action buffer;
        doIO; actionavail := false;
        signal (actiondone)
        end

    end action archive;

  (*initialize device module*)

    begin arnO := 0; drnO := 0; abnO := 0; dbnO := 0;
          dataavail := false; actionavail := false
          dataarchive; actionarchive

    end ACTIVE-ARCHIVE;
```

5.5 IO Control - SWITCH Interface Modules

As shown in Figure 3.8, the subscriber and trunk IO control processes interact with SWITCH via five interface modules: LINEINPUT, NOTICE, REPLY, HEADERS, and LINEOUTPUT. Modula programs for each of these modules are given in Figures 5.7 - 5.11.

LINEINPUT is shown in Figure 5.7. It defines two operations, sendhead and receivehead. Sendhead is called by input control processes; it stores a header in the headers queue and posts a NOTICE to tell SWITCH that a new header has arrived. SWITCH calls receivehead once it receives the NOTICE; it returns the first header. LINEINPUT acts like a simple message passing module except that because SWITCH only calls receivehead when it knows a header is available, receivehead never causes SWITCH to wait.

The NOTICE interface module implements a bounded buffer of notices for SWITCH. Notices are posted from a variety of places whenever SWITCH needs to be told something. They are only received by SWITCH, however. The program for NOTICE is given in Figure 5.8. Each notice has a kind field to tell what kind of data it contains. In Section 5.8 the different

Figure 5.7

LINEINPUT

```
interface module LINEINPUT;
     define sendhead, receivehead;
     use NOTICE, header;
     var headers : queue "max#" of header; (*sent headers*)
          nonfull : signal; (*synchronization*)
     procedure sendhead (hd : header);
          begin
          if headers.size = "max#" then wait(nonfull) end;
          headers.insert (hd);
          NOTICE.post ("head",0)
          end sendhead;

     procedure receivehead (var hd : header);
          begin
               header.delete (hd);
               signal (nonfull)
          end ;
     begin (*headers is initially empty*)
end LINEINPUT;
```

Figure 5.8

SWITCH Notices

```
interface module NOTICE;
     define post,receive;
     type note = record k,d : integer end;
     var nonempty, nonfull : signal; (*synchronization*)
         notices : queue n of note; (*pending notices*)

     procedure  post (kind,data : integer);
          var n : note;
          begin if notices.size = n then wait (nonfull) end;
               n.k. = kind; n.d. = data;
               notices.insert(n);
               send(nonempty)
          end post;

     procedure receive (var kind,data : integer);
          var n : note;
          begin if notices.size = 0 then wait(nonempty) end;
               notices.delete(n);
               kind := n.k; data := n.d;
               send (nonfull)
          end receive ;
     begin  (*notices is initially empty*)
     end NOTICE;
```

values for kind and data are enumerated when SWITCH is discussed.

REPLY is similar to NOTICE and is shown in Figure 5.9. The main difference is that many processes can receive replies; in particular all input and output control processes wait at times for a REPLY. Consequently, REPLY uses an array of signals, one per line number. The receive operation returns an integer data value once it is available. Replies are sent by calling the give operation and specifying the line number and data.

The fourth interface module, HEADERS, provides storage for the headers of all active messages. Its program is shown in Figure 5.10. When SWITCH receives a new header from LINEINPUT, it calls HEADERS.enter. Enter selects a free header "slot" and stores the header in it. The index of the selected slot is returned to SWITCH and becomes the internal identifier of the message. As the message corresponding to the header is processed, the header is occassionally updated by calling retrieve, changing some values, and then calling update. Once the message has been output or cancelled, the header is destroyed by calling delete. Initially all header slots are put on the free queue.

The final interface module connecting IO control processes to SWITCH is LINEOUTPUT, shown in Figure 5.11. Its functions are to schedule and control output activity. For each output line, LINEOUTPUT has a linequeue record which is the header of a list of output messages for that line. For each

Figure 5.9

IO Control Replies

```
interface module REPLY;
    define give,receive;
    var replies : array 1 : "#lines" of integer;
        available : array 1 : "#lines" of signal;
        i : integer;
    procedure give (line, data : integer);
        replies [line] := data;
        send (available [line])
        end give;

    procedure receive (line : integer; var data : integer);
        if replies[line] = 0 then wait (available[line]);
        data := replies[line];
        replies[line] := 0
        end receive;

    begin  i := 1
        repeat replies[i] := 0; inc(i) until i > "#lines"
    end REPLY;
```

Figure 5.10

Header Storage

```
interface module HEADERS;

     define enter,retrieve,update,delete;

     use header;

     var hd : array 1 : "max #" of header; (*full headers*)
          free : queue "max#" of integer;  (*empty header slots*)
          i : integer;

     procedure enter (h : header, var index : integer);

          var i : integer;
          begin if free.size = 0 then error end;
                free.delete(i); index := i;
                hd(i) := h end enter;

     procedure retrieve (var h : header; index : integer);

          begin h := hd[index] end retrieve;

     procedure update (h : header, index : integer);

          begin hd[index] := h end update;

     procedure delete (index : integer);

          begin free.insert(index) end delete;

     begin  i := 1; (*initialize free list*)

          repeat free.insert(i); inc(i) until i > "max#"

     end HEADERS;
```

output message, the kind of message, its internal name (HEADERS index) and precedence are stored. The msgs array is the storage area for all output messages. Free message slots are kept in the free queue. Each line queue stores messages in decreasing order of precedence. That is, the highest precedence output message is always kept at the head of the list. Within any precedence level, output messages are ordered by time of arrival. The other main variables are a Boolean array of preemption flags set by insert (discussed shortly) and an array of available signals used to synchronize output control processes.

LINEOUTPUT provides four operations: insert, receive, done, and cancel. Insert is called by SWITCH, once for each destination of an input message; it adds an outputmsg to the appropriate output queue. If the output queue is empty, the message goes at the front and available is signalled. If the new output is of higher precedence than the one at the front of the queue, the new message is put at the front and the pre-empt flag for the line is set. This will cause the appropriate output control process to stop and call LINEOUTPUT to receive the new, high precedence message. If the new message is of equal or lower precedence than the one at the front of the queue, it is inserted at the appropriate place.

The receive operation is called by output control processes whenever they are ready to output another message. If none is available, the process waits. When a message is

available the output controller receives the header of the first output message on the linequeue. Some special messages, which are merely directions to output processes, are also sent via LINEOUTPUT. Since these do not have headers, only a kind indicator is returned. Note that received messages remain on the linequeue. In this way they can be received again if pre-empted by higher precedence output.

Once output is complete, the output control process calls done. Done merely deletes the first entry on the linequeue and for regular messages (those having headers) notifies SWITCH. For simplicity, done does not return the next available message if there is one. The output controller gets the next one via receive.

The final operation is cancel. It is called by SWITCH in order to cancel the output of a message (when directed to do so by the operator). Because a message may be sent to more than one destination and may be in different stages of output to those destinations, cancel merely marks the message by setting kind to "cancel". Eventually each output destination controller will receive the message, process the cancellation and call done.

5.6 Subscriber Groups

Each subscriber group provides an interface to a user terminal. The organization of each group is the same and was shown in Figure 3.4. The programs for an SINPUT and an SOUTPUT process as well as a SUBSCRIBER device module

Figure 5.11

Line Output Queues

```
interface module LINEOUTPUT;

     define pre-empt, insert, receive, done, cancel;

     use HEADERS, NOTICE, header;

     type outputmsg = (*output control information*)

          record kind, index, pr : integer;
                 link : integer; end;


          linequeue =  (*list header for line*)

          record front, rear, size : integer; end ;


     var  msgs : array 1 : "max" of outputmsg  (*storage for output
                                                  messages*)
          free : queue "max#" of integer; (*free message slots*)

          outqueue : array 1 : "#lines" of linequeue;  (*queues of
                                                         available messages*)
          pre-empt : array 1 : "#lines" of Boolean;  (*pre-emption
                                                        flags*)
          available : array 1 : "#lines" of signal;  (*output
                                                        synchronization*)
          i : integer;
          doinsert : array 1 : "#lines" of signal; (*pre-emption
                                                     synchronization*)
procedure insert (line, msgkind, msgindex, precedence : integer);
          (*insert output message on outqueue (line) at appropriate
            precedence*)

     var slot : integer

     begin with outqueue(line) do

          free.delete(slot) (*get empty slot-fill in values*)
          with msgs[slot] do
               kind := msgkind; index := msgindex;
               pr := precedence, end
```

Figure 5.11 (Continued)
Line Output Queues

```
if pre-empt [line] then wait (doinsert[line] end;
                         (*avoid pre-emption conflict*)
if size = 0  (*empty linequeue*)

     then front := slot; rear := slot;
          size := 1; msgs[slot]·link := 0;
          send(available[line])  (*wake up output process*]

elseif precedence > msgs[front].pr (*pre-emption*)

     then (*put new message at front*)
          msgs[slot].link := front;
          front := slot; inc(size);
          pre-empt[line] := true;
          NOTICE.post ("pre-empt", msgindex)  (*inform SWI
                                              of pre-emptio

else (*put new message at appropriate spot in linequeue*)

     i := front;

     while i ≠ 0 and precedence <= msgs[i].pr do
           j := i; i := msgs[i].link end;

     if i = 0

          then  (*insert at end of linequeue*)
               msgs[slot].link := 0;
               msgs[rear].link := slot;
               rear := slot

          else (*insert in middle*)
               msgs.[slot].link := i;
               msgs[j].link := slot

          end

     inc(size)

  end (*of conditional*)

 end (*of with*)

end insert;
```

Figure 5.11 (Continued)

Line Output Queues

```
procedure  receive (line : integer; var knd : integer; var
                    hd : header);
                   (*fetch first output message from outqueue (line)
                     as soon as one is available*)

     var i : integer;

     begin with outqueue[line] do

          if size = 0 then wait(available[line]) end;

               (*retrieve first message*)
               knd := msgs[front].kind
               if knd = "newmsg" or "acknowledgeinput"
                    then HEADERS.retrieve (hd,msgs[front].index)

                         end

               pre-empt[line] := false;
               send (doinsert[line]);(*let another pre-emption*)
                                     (*occur if one is pending*)

               end
     end receive;


procedure done (line : integer);
     (*called when last received output message is finished*)

     var f; i : integer;

     begin with outqueue[line]do
          (*delete first entry on queue - if pre-empt [line] then
          f := front;                      delete second entry*)
          front := msgs[front].link;
          if pre-empt[line] (*a pre-emption insert has occurred but
                              has not been recognized*)
             then f := front; front := msgs[front].link end

          free.insert(f);
          dec(size)
          if rear = f then rear := 0 end
```

Figure 5.11 (Continued)

Line Output Queues

```
        (*tell SWITCH output is complete for regular messages*)
        i := msgs[f].index;
        if i > 0 then NOTICE.post("done",i) end
        end
    end done;

procedure cancel (ind : integer);
        (*find and mark any output messages identified by
          ind - the message may be in more than one linequeue -
          for each copy of the message set kind to "cancel:
          and, if it is at the front of the queue, set the
          pre-empt flag*)
    var ℓ : integer; hd : header; cnt, ptr : integer;
    begin
        HEADERS.retrieve (ind,hd)
        cnt := 1;
        repeat (*for each output destination in header*)
            ℓ := hd.dests[cnt]; (*line# of destination*)
            with outqueue[ℓ]do
                ptr := front;
                while ptr <> 0 do
                    if msgs[ptr].index = ind
                        then msgs[ptr].kind := "cancel"
                            if ptr = front then
                                pre-empt[ℓ] := true end
                        end
            inc(cnt);
        until cnt > hd.outputcount
    end cancel;
```

Figure 5.11 (Continued)

Line Output Queues

```
begin  (*initialize LINEOUTPUT variables*)
     i := 1;
     repeat pre-empt[i] := false
     until i > "#lines";

     i := 1
     repeat free.insert(msgs[i])
     until i > "max"

end LINEOUTPUT;
```

are shown in Figures 5.12 - 5.14. Because Modula does not provide any means to declare processes or modules as types, an actual system must contain one group of these three components for each subscriber terminal.

An SINPUT process takes the actions shown in Figure 4.1. Its role is to read characters from a terminal (via its SUBSCRIBER device module) and group the characters into headers and blocks. The program is shown in Figure 5.12. SINPUT is organized as a loop repeated for each character. First the character is read and then an action is taken depending on the current status of input. There are three states: find start, in head, and in body.

When no message is being processed, SINPUT is in "find start" status and looks for a start of message sequence of characters. Once the start has been found, status changes to "in head". Subsequent characters are parsed (detailed code is not shown since it depends on the exact message format) and a header is built. When the end of the header input is detected, a memory file is created, the header is archived, the header is sent to SWITCH (via LINEINPUT) and status is changed to "in body". The character sequence comprising the body of the message is then processed. For each block, MEMORY.write and ARCHIVE.data operations are called. Once the end of the message is found, the last block is taken care of and SWITCH is notified. If the message is cancelled, SWITCH is told to cancel input. After detecting the end of

Figure 5.12

Subscriber Input Process

```
process  SINPUT; (*one SINPUT process for each line*)
     use header, block, blocklength, SUBSCRIBER, LINEINPUT,
          REPLY, MEMORY, ACTIVE-ARCHIVE, NOTICE, HEADERS;

     var status : integer; (*where SINPUT is in the message*)
         bl : block;  (*buffer for building input message*)
         hd : header; (*header built for new input*)
         name : integer; (*internal msg identifier*)
         msgid : integer; (*external msg identifier*)
         filename : integer; (*name of MEMORY file*)
         current : integer; (*character pointer into bl*)
         nblocks : integer; (*number of input blocks in a messge*)

     begin  (*initialize variable*)
         status := "find start";

     loop

         SUBSCRIBER.read(ch); (*get next input char*)
         case status of

"find start":  begin
               look for start of message sequence of characters ;
               keep record of where you are in sequence;

               if entire SOM sequence has been received

                    then current := 1;
                         status := "in head"

                    end

               end; (*of find start case*)
```

Figure 5.12 (Continued)
Subscriber Input Process

```
"in head" : begin
            (*store character received*)
            bl.[current] := ch;
            inc(current);

            find next header component in bl;
            store it in hd;
            if error then status := "find start"
                NOTICE.post ("exception", data) end;
            if end of header found then (*tell SWITCH*)
                LINEINPUT.sendhead(hd);
                REPLY.receive (line# i, name);  (*name is internal
                                                 name of message -
                                                 assigned by SWITCH*)
                (*create an auxiliary storage file*)
                MEMORY.create (hd.identity, hd.size, filename);
                    (*filename is assigned by MEMORY*)
                nblocks := 0;
                ACTIVE-ARCHIVE.data( msgid,bl);
                (*set current to start of block and start reading
                  of body of message*)
                current := 1; msgid := hd.identity;
                status := "in body"
            end (*of end of header condition*)
     end; (*of in head case*)
"in body" : begin
            (*store character received*)
            bl(current) := ch; inc(current);
            (*look for end of msg(EOM) or cancel sequence*)

            if end of message then fill rest of bl with blanks;
                (*write block on ARCHIVE And MEMORY*)
                ACTIVE-ARCHIVE.data (msgid, bl);
                MEMORY.write (filename,bl); inc(nblocks);
                MEMORY.endwrite (filename); (*close file*)
                (*store actual size and file name in header*)
                HEADERS.retrieve (hd, name);
                hd.size := nblocks;
                hd.filename := filename;
                HEADERS.update(hd, name);
```

Figure 5.12 (Continued)

Subscriber Input Process

```
          (*notify SWITCH of end of input*)
          NOTICE.post ("end of input", name);
         (*reinitialize*)
          status := "find start"

elseif  cancel input sequence found then
        (*archive block and notify SWITCH*)
        ACTIVE-ARCHIVE.data (msg,bl);
        NOTICE.post ("input cancel", name)
        status := "find start"

elseif  current = blocklength then (*write out block*)
        ACTIVE-ARCHIVE.data (msgid,bl);
        MEMORY.write (filename, bl); inc(nblocks);
        current := 1
        end

    end (*of in body case*)
  end (*of loop*)

  end SINPUT;
```

message or cancel, SINPUT sets status to "find start" and repeats the above actions.

The program for an SOUTPUT process is shown in Figure 5.13. SOUTPUT also executes as a loop receiving an output command from LINEOUTPUT, completely processing the command and then repeating the process by getting another LINEOUTPUT command. (See Figure 4.3) There are six kinds of output commands: new message, acknowledge input, cancel, stop input, restart input, and stop output.

New message is the most common type of command. It is sent whenever SWITCH receives a new input message having SOUTPUT's terminal as a destination. On receipt of a new message command, (which returns the header), SOUTPUT outputs the header (appropriately reformatted) and then outputs each block of the message. Blocks are read from MEMORY; they are printed by calling SUBSCRIBER.write for each character. Because new input of higher precedence may be inserted in LINEOUTPUT (by SWITCH) while SOUTPUT is writing out a message, SOUTPUT needs to know when a preemption is to occur. LINE-OUTPUT communicates with SOUTPUT by setting a pre-empt flag. SOUTPUT periodically checks the flag and, if set, exits the loop. This results in the new, higher precedence message being received from LINEOUTPUT. As coded in Figure 5.13, SOUTPUT checks the pre-empt flag after each block of output. This could readily be changed to character level pre-emption by moving the check (<u>when</u> statement) inside the inner <u>repeat</u> statement.

The second kind of output command is acknowledge input. This is sent by SWITCH to inform the user at a terminal that an input message has been received. The action of SOUTPUT is to send the set of characters "input X received" to the SUBSCRIBER where X is the sequence number from the input message header.

The cancel kind of output comes about when a normal (new message) kind of output is cancelled. In this case, SOUTPUT does not output the message but merely informs the terminal user that output was cancelled. Because of the pre-emption mechanism, output in progress can be cancelled.

The stop input command is used to tell the terminal user to stop sending input. (This command is issued by MEMORY or the operator). At some later time, the restart input command will be received by SOUTPUT who then tells the user to restart input.

The final type of command is used to temporarily stop output. SOUTPUT tells the user that output is being stopped and then waits for a REPLY (from SWITCH). On receipt of the REPLY, SOUTPUT resumes.

After processing any output command, SOUTPUT calls LINEOUTPUT.done and then loops back to receive the next command from LINEOUTPUT.receive.

The final component of each subscriber group is a SUBSCRIBER device module. It provides an interface to one terminal by defining read and write operations called by SINPUT and SOUTPUT, respectively. To effect IO, SUBSCRIBER contains two character buffers, one for input and one for

Figure 5.13

Subscriber Output Process

```
process  SOUTPUT;

     use  header, block, LINEOUTPUT, MEMORY, SUBSCRIBER, NOTICE,
          REPLY;

     const  line = # of output line i;

     var  kind : integer; (*kind of output message*)
          hd : header;     (*header of output message*)
          nblocks : integer  (*number of blocks to output*)
          cblocks : integer  (*number of blocks currently being
                                output*)
          bl : block        (*block of data to output*)
          msgcount: integer  (*count of messages output*)
          i, j : integer    (*local counters*)

     begin (*initialize variables*)
           msgcount := 0;

loop loop (*inner loop is for each output message;outer loop is to
            allow escape from inner loop when pre-emption occurs*)

           LINEOUTPUT.receive (line,kind,hd);

     case kind of

"new msg" : begin
              (*hd contains header of message to output*)
              nblocks := hd.size;
              inc(msgcount);
              (*format output header in bl*)
              (*output header contains :  origin of message
                                          precedence,classification,
                                          identity
                                          local sequence number
                                          (msgcount)*)
           when hd.class is not valid for this terminal
              do NOTICE.post ("exception", invalid classification
                                             on line);
                 LINEOUTPUT.done (line)
                 exit;
```

Figure 5.13 (Continued)

Subscriber Output Process

```
bl := output header;
 i := 1;
repeat  (*output, header on terminal*)
     SUBSCRIBER.write (bl[i]); inc(i)
until i > blocklength;
    (*output contents of message as long as no
      pre-emption occurs*)
    j := 1;
    repeat
        when pre-empt[line] do exit;   (*go back to start
                                         of main loop*)
        MEMORY.read (hd.filename, j, bl);
        i := 1;
        repeat (*output bl*)
               SUBSCRIBER.write (bl[i]);
               inc(i)
        until i > blocklength;
        inc (j)
    until j > nblocks;
end; (*of new msg case*)

"acknowledge input" : begin
        (*tell terminal subscriber that an input message has
          been received by SWITCH- hd contains the header of
          the message*)
        bl := "input X received"; (*X is hd.sequence(i)*)
        i = 1
        repeat
             SUBSCRIBER.write (bl[i]),
             inc(i)
        until  i > # of character in bl;
    end (*of acknowledge input case*)
```

Figure 5.13 (Continued)

Subscriber Output Process

```
"cancel" : begin
             (*cancel output that was in progress - done
               automatically via pre-emption - here merely
               tell terminal operator that message was can-
               celled and then tell LINEOUTPUT that action
               is done*)
            bl := "output cancelled by supervisor";
            i := 1
            repeat
                    SUBSCRIBER.write (bl[i]);
                    inc(i)
            until  i > # chars in bl;
         end (*of cancel case*)

"stopinput" : begin
              (*tell terminal operator to stop input*)
              bl := "stop input until told to restart";
              i := 1;
                 repeat
                       SUBSCRIBER.write (bl[i]);
                       inc(i)
                 until  i >  # chars in bl;
              end (*of stop input case*)

"restart input" : begin
                   (*tell terminal operator to restart input*)
                   bl := "restart input from point where stopped*)
                   i := 1;
                   repeat
                        SUBSCRIBER.write (bl[i]);
                        inc(i)
                   until  i > #chars in bl;
                  end (*of restart input case*)
```

Figure 5.13 (Continued)

Subscriber Output Process

```
"stop output" : begin  (*stop writing output; wait for REPLY
                         to signal proceed.  Will restart output
                         at beginning of stopped message*)
                   bl := "stopping output";
                   i := 1;
                   repeat
                        SUBSCRIBER.write (bl[i]);
                        inc(i)
                   until i > # chars in bl;
                   REPLY.receive (line,kind); (*wait*)
                end (*of stop output case*)
      end;(*of case statement*)
                LINEOUTPUT.done(line)
      end end (*of loops*)
      end SOUTPUT;
```

Figure 5.14

Subscriber Device

```
device module SUBSCRIBER;

     define  read, write;

     var  inr,outr, nrf : integer; (*input buffer vars*)
          non r full, non r empty : signal; (*input signals*)
          rbuf : array 1 : n of char; (*input buffer*)

          inw, outw, nwf : integer; (*write vars*)
          nonwfull, nonwempty : signal; (*output signals*)
          wbuf : array 1 : n of char; (*output buffer*)


     procedure  read (var ch : char);

          begin (*retrieve next input character from rbuf*)

               if nrf = 0 then wait (nonrempty) end;
               ch := rbuf [outr];
               outr := (outr mod n) + 1
               dec(nrf);
               send(nonrfull);

          end read;

     procedure  write (var ch : char);
          begin  (*deposit ch in output buffer*)
               if nwf = n then wait(nonwfull) end;
               wbuf[inw] := ch; inw := (inw mod n) + 1;
               inc(nwf); send (nonwempty)

          end  write

     process input;
             (*input chars as long as rbuf is not full*)
          begin
               loop
               if nrf = n then wait (nonrfull) end;
                  start read into buf[inr]; doIO;
                  inr := (inr mod n) + 1
                  inc (nrf);
                  send (nonrempty);
          end
       end input;
```

Figure 5.14 (Continued)

Subscriber Device

```
process  output;
        (*output chars as long as wbuf is not empty*)
    begin
        loop

            if nwf = 0 then wait (nonwempty) end;
            start output of buf[outw];
            doIO;
            outw := (outw mod n) + 1;
            dec(nwf)
            send(nonwfull);
        end
    end output
begin
inr := 1; outr := 1; nrf := 0; input;
inw := 1; outw := 1; nwf := 0; output

end SUBSCRIBER;
```

output. The procedures and processes synchronize with each other via counters, pointers and signals. Each buffer is treated as a circular queue where characters are deposited at one end and removed from the other. The SUBSCRIBER code is shown in Figure 5.14.

5.7 Trunk Groups

A trunk group provides an interface to a trunk line connecting one switching node to another. Each group has the same organization as a subscriber group (Figure 3.4). It contains TINPUT and TOUTPUT processes and a TRUNK device module. Code for these components is shown in Figures 5.16 - 5.18. As with subscribers, an actual system must contain one group for each trunk line.

The actions of each TINPUT and TOUTPUT process are basically the same as those of the SINPUT and SOUTPUT processes. The differences are that trunks transmit blocks instead of characters and that numerous control characters are used to control synchronization. Figure 5.15 defines a <u>type</u> for a trunkblock and also defines the kinds of control characters used for synchronization. Data blocks sent along trunk lines are 84 characters long. The control character at the start of a block is SOH or STX for the first and subsequent blocks of a message, respectively. The end character is ETX or ETB for the last and all previous blocks, respectively. Trunk blocks also contain a select character which defines the code used (e.g. ASCII), a parity, and 80

Figure 5.15

Trunk Blocks and Control Characters

```
type trunkblock

      record  control, select : char;
              data : block; (*block = array of chars*)
              end,parity : char end;
```

Control Characters to Synchronize Transmission:

Kind	Meaning
ACK1, ACK2	acknowledge last block; alternate ACK1, ACK2, ACK1, ACK2, etc.
NAK	non-acknowledge of block
STOP	stop transmission
RESTART	restart transmission
SYN	synchronize - used to keep line active when no data is being transmitted
CAN	cancel transmission
INV	invalid transmission
REP	repeat last block
RM	error - unable to frame block

Control Characters to Frame Blocks:

SOH	start of header
STX	start of non header block
ETB	end of block but not end of message
ETX	end of message

characters of data.

For each data block transmitted, at least one control character is returned. Normally this acknowledges receipt of the block (ACK 1 or ACK 2). Exceptions can occur, however, and are indicated by the other control characters. In order to understand this message protocol in detail, the code for TINPUT and TOUTPUT should be studied carefully.

The TRUNK device module provides five operations: read, write, write control, post control and wait control. Read and write are used to transmit data blocks. The other operations are used to transmit and synchronize control characters. Write control is used to output a control character; it is called by TINPUT to respond to an input block. Waitcontrol is called by TOUTPUT to wait for a response from the prior output of a data block. The response is sent by the switching node at the other end of the trunk line and consequently, is received as input by TINPUT. Since TINPUT and TOUTPUT are processes, they can only communicate via an interface module. Therefore TINPUT passes control characters to TOUTPUT by calling the post control operation of TRUNK.

We now turn to the code of the processes. TINPUT (Figure 5.16) receives a trunk block, processes the information in the block and then loops. The TRUNK device module determines the type of input in each trunk block. There are three input types handled by TINPUT: error, control, and message.

If an input error occurs, meaning that TRUNK read an

invalid first character, TINPUT writes an RM (unable to frame) control character on the output line of the trunk by calling TRUNK.writecontrol. The switching node at the other end of the trunk will then send a cancel character to TINPUT. (see the code for TOUTPUT, Figure 5.17, since the output process at the other end of the trunk is in fact a TOUTPUT process of the other switching node).

If TINPUT reads a control character, it looks at the character and then takes an appropriate action. Characters which are responses from output are sent to TOUTPUT by calling TRUNK.writecontrol. A SYN character merely keeps the line "alive" so TINPUT does nothing. A CAN (cancel) character causes TINPUT to cancel input processing and notify SWITCH. An INV (invalid) character indicates problems so SWITCH is notified of an exception. Finally a REP (repeat) character should not occur so will be ignored.

The third type of input is message. This means that the TRUNK device module read a data block beginning with an SOM or STX control character. In this case, TINPUT processes the block in the same manner as SINPUT: header blocks are parsed and sent to LINEINPUT; a file is created for new messages; and blocks are written on MEMORY and the ACTIVE-ARCHIVE. When the last block of a message is read, SWITCH is notified.

TOUTPUT has the same organization as SOUTPUT (Section 5.6, Figure 5.13). Its program is given in Figure 5.17. TOUTPUT receives an output command from LINEOUTPUT and processes the command. There are five types of commands (the same ones as

Figure 5.16

Trunk Input Process

```
process TINPUT;  (*one copy per trunk*)

     use block, header, trunkblock, TRUNK, NOTICE, REPLY,
         MEMORY, LINEINPUT, ACTIVE-ARCHIVE, HEADERS;

     var  bl : block;        (*data block for MEMORY*)

          head : header;          (*header for input message*)
          tbl : trunkblock;       (*input block from TRUNK*)
          cchar : char;           (*input control character*)
          intype : integer;       (*type of input from TRUNK*)
          status : integer;       (*status of msg - find start or in bod
          name : integer;         (*internal message id*)
          filename : integer;     (*id of memory file*)
          nblocks : integer;      (*number of blocks in msg*)
          ackn0 : integer;        (*1 or 2 for ACK1 or ACK2*)

          msgid : integer;        (*external id of message*)

     begin (*initialize variables*)
             status := "find start";
             ackn0 := 1;

     loop TRUNK.read (tbl, intype); (*get next input*)

          case intype of

     error : (*invalid first character in input - unable to
                frame input*)

             begin TRUNK.writecontrol("RM") end;

     control : (*input is a control character*)

          begin

               cchar := tbl.control; (*fetch control character*)

               if cchar = "ACK1" or char = "ACK2" or char = "NAK"
                  or char = "STOP" or char = "RESTART"

                  then(*give TOUTPUT the control character*)

                      TRUNK.postcontrol (cchar)

               elseif cchar = "SYN"

                  then (*do nothing - merely line synchronization
                          character so just do next read*)
```

Figure 5.16 (Continued)

Trunk Input Process

```
            elseif cchar = "CAN"
                 then (*cancel input if in msg - otherwise ignore*)
                      if status = "inbody"
                           then (*tell SWITCH to cancel*)
                                NOTICE.post ("input cancel",name);
                                status := "find start";
                                acknO := 1;  end

            elseif cchar = "INV"
                 then (*unsolicited answer*)
                    NOTICE.post ("exception", number)

            elseif cchar = "REP"
                 then (*repeat character - will ignore for now -
                           will assume acknowledgement has been sent*)

            else (*error*)
                   TRUNK.writecontrol ("RM")

            end
       end (*of control case*)


msg : (*input is a block of a message*)
      (*it starts with an SOM or STX control character*)
     begin
          check parity of trunkblock tbl and check control characters
            if input is in error
                 then TRUNK.writecontrol ("NAK")
            else (*acknowledge receipt of input*)
                 if acknO = 1 then TRUNK.writecontrol ("ACK1");
                                        acknO := 2
                      else writecontrol ("ACK2"); acknO := 1 end;
```

Figure 5.16 (Continued)

Trunk Input Process

```
        if tbl.control = "SOH"
             then (*start of message header*)
                       parse contents of tbl to build head;
                       LINEINPUT.sendhead (head);
                       REPLY.receive (trunk line #, name);
                            (*name is internal msg id*)
                       (*create an auxiliary storage file*)
                       MEMORY.create (head,identity, hd.size,
                                      filename);
                       nblocks := 0;
                       status := "in body"
                       ACTIVE-ARCHIVE.data (hd.identity, tbl.data);

        elseif tbl.control = "STX" and tbl.end = "ETB"
             then  (*block of message - not end*)
                       bl := tbl.data; (*message itself*)
                       MEMORY.write (filename,bl);
                       ACTIVE-ARCHIVE.data(msgid,bl);
                       inc(nblocks)

        elseif tbl.control = "STX" and tbl.end = "ETX"
             then  (*end of message*)
                       bl := tbl.data;
                       MEMORY.write (filename, bl);
                       MEMORY.endwrite (filename);
                       inc(nblocks);
                       ACTIVE-ARCHIVE.data (msgid,bl);
                       (*store file size and filename in header*)
                       HEADERS.retrieve (hd, name);
                       hd.size := nblocks;
                       hd.filename := filename;
                       HEADERS.update (hd, name);

                       (*notify SWITCH and reinitialize*)
                       NOTICE.post ("end of input", name);
                       status := "find start"
                       ackn0 := 1;
        end (*of conditional*)
        end (*of conditional*)
    end (*of msg case*)
  end (*of loop*) .

end TINPUT;
```

for SOUTPUT): new message, cancel, stop input, restart input, and stop output.

On receipt of a new message command, TOUTPUT fetches and outputs each block of the message. The header is first reformatted. Then TOUTPUT repeatedly writes a trunk block, waits for a control character response (actually read by TINPUT), checks for pre-emption and processes the control character. Iteration continues until either output is pre-empted, all blocks are written or an error occurs. If the control character correctly acknowledges the previous write then the next block (if any) is read from MEMORY. If the previous TRUNK write is not acknowledged, output is re-tried (up to some number, n, times). If the control character indicates that the output was in error then output is cancelled and SWITCH is notified.

The cancel, stop input, or restart input commands respectively cause a CANCEL, STOP, or RESTART control character to be written on the output line. The stop output command causes TOUTPUT to wait for a REPLY.

After any command is processed, TOUTPUT calls LINEOUTPUT to say that it is done. TOUTPUT then receives the next output command.

The final trunk component is the TRUNK device module. As mentioned before, it defines five operations: read, write, write control, post control, and wait control. Actual output is carried out by driver processes named input and output. Input fills a trunk block buffer for read. Output empties

Figure 5.17

Trunk Output Process

```
process TOUTPUT;  (*one copy per trunk*)

     use header, trunkblock, block, LINEOUTPUT, MEMORY, NOTICE,
         REPLY, TRUNK;

     const  line = # of output line for trunk;

     var  kind : integer;            (*kind of output message*)
          head : integer;            (*header for output message*)
          nblocks : integer;         (*number of blocks to output*)
          cblock : integer;          (*number of block currently being
                                                      output*)

          tbl : trunkblock;          (*output to TRUNK*)
          bl : block;                (*data from MEMORY*)
          cchar : char;              (*control character*)
          acknO : integer;           (*1 or 2 for ACK1 or ACK2*)
          more : Boolean;            (*control for output loop*)
          NAKtries : integer;        (*number of tries at retransmissi
          REPtries : integer;        (*number of waits for response*)

     begin  (*initialize variables*)

              NAKtries := 0;
              REPtries := 0

loop loop (*inner loop executed once per LINEOUT msg*)
          (*outer loop allows escape on preemption*)

     LINEOUTPUT.receive (line, kind, head);

     case kind of

new msg : begin  (*head contains header of message to output*)

          nblocks := hd.size; (*no. of blocks to output*)

          (*format output header in tbl.data - origin of message,
            identity, precedence, classification sequence numbers*)
          tbl.data := header contents as above;
          tbl.control := "SOH";
          tbl.end := "ETB";
          tbl.parity := block parity;
          more := true; acknO := 1; cblock := 0;
```

Figure 5.17 (Continued)

Trunk Input Process

```
(*main output loop - executed once for each message block*)
while more do
     TRUNK.write (tbl);
     TRUNK.wait control (cchar);
     (*check pre-emption*)
     when  pre-empt [line] do
          TRUNK.writecontrol ("CAN") (*cancel*)
          exit;

(*control may say to STOP; if so wait for restart*)

if cchar =  "STOP" then while cchar ≠ "RESTART" do
                            TRUNK.waitcontrol (cchar) end
                   end;
          (*take action depending on value of cchar*)

if (cchar = "ACK1" and ackn0 = 1) or
   (cchar = "ACK2" and ackn0 = 2) then (*valid response*)
    inc(cblock);
    if cblock >nblocks then more := false (*output complete*)
    else (*get next block and build output block*)
          MEMORY.read (head.filename, cblock, bl);
          tbl.control := "STX"
          if cblock = nblock
               then tbl.end := "ETX"
               else tbl.end := "ETB" end;
          tbl.data := bl;
          tbl.parity := block parity;
          if ackn0 = 1 then ackn0 := 2
                       else ackn0 := 1 end
     end
elseif cchar = "NAK"
     then  (*do nothing - will retransmit same block - but
             if done more than n times notify supervisor
             and get next output*)
          inc (NAKtries);
```

Figure 5.17 (Continued)

Trunk Output Process

```
            if NAKtries >  n then NOTICE.post ("exception", #)
            NAKtries := 0;
                 more := false (*stop trying - go to next output*)
            end

  elseif cchar = "RM"
       then  (*unable to frame - send cancel and notify local
               supervisor*)

            TRUNK.writecontrol("CAN");
            NOTICE.post("exception", n0);
            more := false; (*get next output*)

  else (*cchar = "NONE" or is invalid*)
             (*TRUNK got no response in expected time - send
               REP to other trunk*)
            inc(REPtries);
            if REPtries < 8
                 then  (*ask again*)
                         Trunk_i.writecontrol ("REP")

                 else (*cancel and tell supervisor*)
                         Trunk.writecontrol ("CAN");
                         NOTICE.post ("exception", n0);
                         more := false;
                         REPtries := 0
                 end
  end (*of conditional statement*)
  end (*of while loop*)
 (*end of message output*)

  end; (*of new msg case*)

cancel : (*cancel output in progress - requested by supervisor*)
  begin
       TRUNK.writecontrol ("CAN");
  end; (*of cancel case*)
```

Figure 5.17 (Continued)

Trunk Output Process

```
  stop input : (*tell output process on other end of the trunk to
                 stop sending input*)
         begin
              TRUNK.writecontrol ("STOP")
         end; (*of stop input case*)

restart input : (*tell output process on other end of trunk to restart
                  sending input*)
         begin
              TRUNK.writecontrol ("RESTART")
         end; (*of restart input case*)

   stop output:  (*temporarily stop sending output - signalled by
                   the supervisor*)
         begin
              (*wait for reply signal to proceed*)
              REPLY.receive (line, kind)
         end;  (*of stop output case*)
      end; (*of case statement*)
      LINEOUTPUT.done (line) (*tell LINEOUTPUT that output message
                               has been processed*)
      end end (*of loops*)
      end TOUTPUT;
```

either the control character buffer filled by writecontrol or a trunk block buffer filled by write. Single buffers are used so input and output synchronize with the operations via Boolean and signal variables. The code of each part of TRUNK is straightforward and is shown in Figure 5.18.

An interesting aspect of trunks is the timing of physical input and output. Input is received one character at a time until either a control character or entire block has been read. Similarly output puts one character at a time on the trunk's output line. We assume that trunks do not give interrupts but instead provide or expect characters to be periodically input or output. Therefore Modula's doIO statement is not used. Instead, the drivers synchronize by waiting for trunkticks which are periodically supplied by the CLOCK process (Figure 5.3). This is quite different from the interrupt drive IO used in a SUBSCRIBER (Figure 5.14).

5.8 Switch Process

The SWITCH process controls all activity in the switching node. It accepts new input from input control processes, generates output commands, communicates with the operator, and handles all exceptions. Its interface to other modules was shown in Figure 3.8 and its actions were summarized in Figure 4.2. Its program is listed in Figure 5.19.

All communication to SWITCH is via the NOTICE interface module. SWITCH repeatedly receives a notice and processes it. At the start of Figure 5.19, a large comment outlines

Figure 5.18

Trunk Device

```
device module TRUNK; (*one per trunk line*)

     define  read,write,writecontrol,postcontrol,waitcontrol;

     use trunkblock, trunktick;

     var   inbuf, outbuf : trunkblock;
           intype : integer;
           outcchar, postchar : char;
           infull,outfull, outcfull, postfull : Boolean;

           doread, readdone : signal;
           dopost, postavail : signal;
           outbufempty, outccharempty : signal;

     procedure  read (var tbl: trunkblock; var kind : integer);

          begin  (*get next input from trunk line*)
               if not infull then wait (readdone) end;
               tbl := inbuf;
               kind := intype; (*control, msg, or error*)
               infull := false;
               send (doread)
               end read;

     procedure  write (tbl : trunkblock);

          begin (*fill buffer - output process will test outfill*)
               if outfill then wait (outbufempty) end;
               outbuf := tbl;
               outfull := true

          end write;

     procedure  writecontrol (c : char);

          begin  (*fill control character buffer*)
               if outcfull then wait (outcchar empty) end;
               outcchar := c;
               outcfull := true

          end writecontrol;
```

Figure 5.18 (Continued)

Trunk Device

```
procedure  postcontrol (c : char);

     begin (*fill post character buffer*)
          if post full then wait (dopost) end;
          postchar := c;
          postfull := true;
          send (postavail)
     end postcontrol;

procedure waitcontrol (var c : char);

     begin  (*get posted character when available*)
          if not postfull then wait (postavail) end;
          c := postchar;
          postfull := false;
          send (dopost)
     end waitcontrol;

process input;
               (*do trunk input into inbuf*)
     var : nch : integer; (*no. of character read*)

begin
     loop
          if infull then wait (doread) end;
          (*get first character*)
          wait (trunktick); (*clock synchronization*)
          inbuf.control := first character on line;

          if inbuf.control has even parity
               then (*control character*)
                    intype := "control"
          elseif inbuf.control = "SOH" or
                 inbuf.control = "STX"
             then (*message block*)
                 intype := "msg"
          else intype := "error"
```

Figure 5.18 (Continued)

Trunk Device

```
        if intype = "msg" then (*input block*)
              wait (trunktick);
              inbuf.select := next char;
              nch := 1;
              repeat wait(trunktick);
                     inbuf.data[nch] := next char;
                     inc(nch)
              until nch > blocklength;
                     wait(trunktick);
                     inbuf.end := next char;
                     wait (trunktick);
                     inbuf.parity := next char
                     end (*of block input*)
              infull := false;
              send (readdone)
        end (*of loop*)
    end input;


process output
      (*output control characters from outcchar or blocks
        from outbuf or, if both are empty, output a line
        synchronization signal*)
    var  nch : integer; (*character count*)
begin
    loop
        wait (trunktick); (*clock synchronization*)
        if outcfull then (*output control character*)
            put contents of outcchar on line;
            outcfull := false;
            send (outcchar empty)
    elseif outfull then (*output block*)
        put outbuf.control on line;
        wait (trunktick);
        put outbuf.select on line;
        nch := 1;
```

Figure 5.18 (Continued)

Trunk Device

```
        repeat wait (trunktick);
             put outbuf.data [nch] on line;
             inc(nch)
        until nch > blocklength;
        wait (trunktick);
        put outbuf. end on line;
        wait (trunktick);
        put outbuf. parity on line;

        outfull := false;
        send (outbufempty)
   else (*output SYN character - there is no real output
          so just keep line synchronized*)
         put "SYN" on line
   end (*of conditional*)
end (*of loop*)
end output;

begin (*initialize TRUNK*)
   unfull := false; outfull := false; outcfull := false;
   postfull := false;
   input; output
end TRUNK;
```

the program and enumerates the kinds of notices. The actions SWITCH takes for each notice will now be discussed in the order in which they appear in the program.

A "head" notice, sent by LINEINPUT, signals the presence of a new header. SWITCH receives the header from LINEINPUT and records control information for the new message. The header is entered into HEADERS, a name table entry is constructed, and an action message is sent to ACTIVE-ARCHIVE and the operator. Finally a REPLY is given to the input control process which input the header.

The largest case SWITCH handles occurs when an input control process sends an "end of input" notice. First, the header is retrieved from HEADERS. Second, the "end of input" action is recorded on the archive and sent to the operator. Third, for input from local subscribers, an acknowledgement is sent to the subscriber via LINEOUTPUT. Fourth, potential message orbit is checked for. An orbit occurs if a message ever comes back to a switching node which has previously processed it. This could happen if directory entries (see below) are erroneous or if trunk lines go down so two switching nodes use each other as alternate routes to a third node. An orbit is detected as follows. When a message is output, SWITCH stores the local switching nodes' identity in the sequence array of the message header. On input, SWITCH looks to see if its identity is already in sequence. If so an orbit has occurred and the operator is informed (he will most likely cancel the message). The fifth action SWITCH

takes on "end of input" notices is to format output commands. For each destination, the directory is consulted to find the first line with "ok" status. If one is found, the header is inserted in LINEOUTPUT. If none is found the operator is informed. After all destinations have been processed, the header is put back in HEADERS for future reference.

Once output completes at any destination, LINEOUTPUT posts a "done" notice. SWITCH decrements the output count (number of destinations) of the message. If the count becomes zero, SWITCH then archives an "output complete" action, tells the operator, deletes the header from HEADERS and destroys the message's MEMORY file.

The above three kinds of notices ("head", "end of input", and "done") pertain to normal message processing. The other kinds should occur much less frequently since they pertain to exceptions and operator requests.

The "stop" notice is issued by the operator or MEMORY to stop input or output. SWITCH sends an output command to the output controller for the line. To restart IO, a "restart" notice is sent to SWITCH. Input is restarted by sending an output command to the subscriber or trunk. Output is restarted by giving a REPLY.

In order to allow the operator to monitor system status, SWITCH also accepts a "status" kind of notice. Its actions are to retrieve the appropriate status value(s), format a message, and send it to the operator. Details for each type of status which might be useful are left unspecified here.

If an input control process finds the cancel sequence of characters in an input message, it notifies SWITCH. SWITCH cancels a message by deleting its header and destroying its file. As usual, the archive and operator are informed.

Output can be cancelled at the request of the operator. To cancel a message, first its internal name is looked up in the names table. If it is not found the operator is informed. If it is found, the message's header is retrieved. If the message has previously been sent to LINEOUTPUT, LINEOUTPUT.cancel is called. (The message may not have been sent because an orbit might have occurred). Cancellation is then archived, the header deleted, and the file destroyed.

The next case processes "exception" notices. The types of exceptions currently implemented deal with archive tapes. Others would also exist in an actual implementation. For each type of exception, a message is formatted and sent to the operator.

"Alter" notices are sent by the operator to alter the contents of either the directory or the line status table. SWITCH receives the new values from SUPERVISOR and stores them in the appropriate table entry.

The final kind of notice signals a pre-emption. When LINEOUTPUT sets a pre-empt flag (except on cancel), he notifies SWITCH who in turn tells the operator.

The complete listing of SWITCH follows as Figure 5.19.

Figure 5.19

Switch Process

```
process SWITCH;

    use NOTICE, LINEINPUT, LINEOUTPUT, HEADERS, REPLY, ACTIVE-
        ARCHIVE, SUPERVISOR, timeofday, header, actionmsg, operator-
        output, operatorrequest

    type  name = record      (*controls for active messages*)
                 msgid, intname : integer;
                 outputcount : integer
                 end;
          destination = record  (*trunk or subscriber line no's*)
                 primary, alt 1, alt 2 : integer
                 end;

    var  names : array 1 : max# activemsgs of name; (*of active mes-
                                                      sages*)
         directory : array 1 : #destinations of destinations;
         linestatus : array 1 : #lines of integer;

         kind,data : integer;        (*input from NOTICE*)
         hd : header;                (*local storage for input header*
         index : integer;            (*internal message name*)
         actmsg : actionmsg;         (*output to archive*)
         line : integer;             (*output line number*)
         c,d,i : integer;            (*counters*)
         orbit : Boolean;            (*message in loop*)
         opout : operatoroutput;     (*output to SUPERVISOR*)
         opreq : operatorrequest; (*input from SUPERVISOR*)
          (* * * * * * * * * * * * * * * * * * * * * * *

         body of switch is a loop with a case statement for
         each kind of NOTICE SWITCH receives - the kinds of
         notices are the following:

    loop NOTICE.receive (kind, data)
         case kind of

    "head" :            data is 0          - new header from LINEINPU
    "end of input" :    data is internalid - end of input
    "done" :            data is internalid - end of output
    "stop" :            data is line#      - stop a line
    "restart" :         data is line#      - restart a line
    "status"  :         data is key for
                          type of status   - send status to operator
    "input cancel" :    data is internalid - cancel message
    "output cancel" :   data is externalid - cancel message
```

Figure 5.19 (Continued)

Switch Process

```
"exception" :      data is key for
                   type of exception -  print message on operator's
                                                   console
"alter" :          data is 0         -  get operator request to
                                        alter directory or line
                                        status from SUPERVISOR
"pre-emption" :    data is msgid     - inform operator

     end

end
  * * * * * * * * * * * * * * * * * * * * * * * * * *)

begin    (*initialize tables*)
         (*details not shown*)

loop  NOTICE.receive (kind, data);
      case kind of

"head" :  begin (*get new header*)
          LINEINPUT.receivehead (hd);
          hd.status := "in input" ;
          HEADERS.enter (hd,index);
               (*fill in name table*)
          with names(index) do
               msgid := hd.identity; intname := index;
               count := hd.#destinations end;
               (*archive receipt of header*)
          with actmsg do
                msgid := hd.identity; time := timeofday;
               action := "header received" end
          ACTIVE-ARCHIVE.action (actmsg);
               (*inform operator of action*)
          SUPERVISOR.sendoutput (actmsg);
          LINEOUTPUT.insert (operator, "output", o, low precedence);
               (*tell input to proceed*)
          REPLY.give (hd.origin, index)

      end (*of head case*)
```

Figure 5.19 (Continued)

Switch Process

```
"end of input" : begin

     index := data; (*internal msg identifier*)
     HEADERS.retrieve (hd, index);
          (*archive end of input*)
     with actmsg do
          msgid := hd.identity; time := timeofday;
          action := "end of input" end;
     ACTIVE-ARCHIVE.action(actmsg);
     SUPERVISOR.sendoutput (actmsg);
     LINEOUTPUT.insert (operator, "output", 0, low);
          (*acknowledge receipt of input if sender is a
            local subscriber*)
     if hd.origin is a subscriber
          then LINEOUTPUT.insert (hd.origin, "acknowledge-
                                  input", index, low)  end;
          (*check for message orbit*)
     with hd do
          i := 1; orbit := false;
          while (i <= seqcount and not orbit)
               do if sequence (i) = local switch#
                    then orbit := true end;
                  inc(i) end;
          end
     if orbit
          then (*output message to operator*)
               format orbit message
               SUPERVISOR.sendoutput (operator output)
               LINEOUTPUT.insert (operator, "operatoroutput",
                                  0, low precedence)
               hd.status := "orbit"; HEADERS.update (hd, index)
     else (*proceed to output message to each destination*)

          with hd do status := "output";
               (*update sequence data*)
               inc(seqcount); sequence (seqcount) := local switch#
               (*output to each destination*)
               c := names (index).outputcount; (*#dests*)
               i := 1;
```

Figure 5.19 (Continued)

Switch Process

```
                repeat
                     d := destinations(i);
                     line := directory(d).primary;
                     if linestatus(line) ≠ "ok"
                     then line := directory(d).alt 1
                     if linestatus(line) ≠ "ok"
                     then line := directory(d).alt 2
                     if linestatus(line) ≠ ok
                     then format no good line message;
                          SUPERVISOR.sendoutput (message);
                          LINEOUTPUT.insert (operator, "operator
                                                output", O, low)
                     end end end;

                     if linestatus(line) = ok then
                     LINEOUTPUT.insert(line, "new msg", index,
                                          prec) end;

                     hd.dests(i) := line;
                     inc(i)
                until i > c;
                (*update header*)
                HEADERS.update (hd, index)
          end (*of end of input case*)

"done" : begin  (*output to one destination is complete*)

             index := data; (*identifies message*)
             dec(names(index).outputcount);

               (*if output is all complete - archive completion
                 and delete message from system*)
             if names (index).outputcount = 0
                  then
                  with actmsg do
                       msgid := names(index).msgid; time := timeofday;
                       action := "output complete" end;
```

Figure 5.19 (Continued)

Switch Process

```
            ACTIVE-ARCHIVE.action (actmsg);
            SUPERVISOR.sendoutput (actmsg);
            LINEOUTPUT.insert (operator, "output", 0, low);
            (*delete header and destroy memory file*)
            HEADERS.delete (index);
            MEMORY.destroy (names (index).msgid)

            end

        end (*of done case*)


"stop" : begin  (*stop IO on one line - done by sending a message
                  to the output process associated with the line -
                  If the line is an input  line, its output partner
                  will send a message to the human or other switchin
                  node telling it to stop input*)
                line := data; (*identifies line #*)
                if line is an input line
                    then line := output partner's line nO
                         LINEOUTPUT.insert (line, "stop-input", 0,
                                             highest precedence)
                    else LINEOUTPUT.insert (line, "stop-output", 0,
                                             highest precedence)
                    end
        end (*of stop case*)


"restart" : begin  (*restartIO - technique is same as above*)
                line := data;
                if line is an input line
                    then line := output partner's line no.
                         LINEOUTPUT.insert (line, "start-input", 0,
                                             highest precedence)
                    else (*output process has gone to sleep because
                           of stop message*)
                           REPLY.give (line,0)
                    end

            end (*of restart case*)
```

Figure 5.19 (Continued)

Switch Process

```
"status" : begin

        (*data identifies type of status requested -
          possible types are
           1. status of line
           2. directory entry
           3. queue lengths, etc. *)

        (*for the status - SWITCH formats a message*)

        opout.data :- contents of message;
        opout.size := length of message;

        (*send message to operator*)
        SUPERVISOR.sendoutput (opout);
        (*tell operator output process a message is in
          SUPERVISOR for him*)
        LINEOUTPUT.insert (operator, "output", 0, high)

    end (*of status case*)


"input cancel" : begin  (*sent by an input process to cancel
                          input of a message*)
        index := data; (*identifies message*)

        (*archive cancel action*,

        with actmsg do

             msgid := names (index).msgid; time := timeofday;
             action := "cancelled input" end;

        ACTIVE-ARCHIVE.action(actmsg);
        opout.data := "cancelled input";
        opout.size := 15;
        SUPERVISOR.sendoutput (opout);
        LINEOUTPUT.insert (operator, "output", 0, low);

        (*delete header and destroy memory file*)
        HEADERS.delete(index);
        MEMORY.destroy(names (index).msgid)

    end (*of input cancel case*)
```

Figure 5.19 (Continued)

Switch Process

```
"output cancel" : begin  (*sent by operator to cancel output*)
                  (*data gives external message identifier*)
                  (*find internal name*)
                  i := 1; index = 0;
                  repeat
                       if names (i).msgid = data
                         then index := names(i),internal id end;
                       inc(i)
                  until index ≠ 0 or i > max# activemessages;
                  if index = 0
                       then (*message not found*)
                           opout.data := "message not found"
                           opout.size := 17;
                           SUPERVISOR.sendoutput (opout);
                           LINEOUTPUT.insert (operator, "output",
                                              0, high);
                  else
                       HEADERS.retrieve (hd, index);
                       if hd.status = "output"
                           then (*tell each output destination to
                                  cancel by telling LINEOUTPUT*)
                                LINEOUTPUT.cancel (index) end;
                           (*archive cancellation*)
                           with actmsg do
                                msgid.:= names (index).internal id;
                                time := timeofday;
                                action := "output cancelled" end
                           ACTIVE-ARCHIVE.action (actmsg);
                           opout.data := "output cancelled";
                           opout.size := 15;
                           SUPERVISOR.sendoutput (opout);
                           LINEOUTPUT.insert (operator, "output",
                                              0, low);
                           (*delete header and destroy memory file*)
                           HEADERS.delete (index);
                           MEMORY.destroy (names(index).msgid)
                     end (*of conditional*)
              end (*of output cancel case*)
```

Figure 5.19 (Continued)

Switch Process

```
"exception" : begin
                (*print exception message on operator's console*)
                (*data identifies exception type*)
                case date of
"mountaction tape" :  begin  opout.data := "mount new action tape on
                                            active archive";
                             opout.size := length of data end;
  "mountdata tape" :  begin  opout.data := "mount new data tape on
                                            active archive";
                                            opout.size := length of
                                                          data end;
 "end action tape" :  begin  opout.data := "end of action tape on old
                                            archive";
                                            opout.size := length of
                                                          data end;
   "end data tape" :  begin   opout.data := "end of data tape on
                                             old archive";
                                            opout.size := length of
                                                          data end;
          end (*of case statement*)
          SUPERVISOR.sendoutput (opout);
          LINEOUTPUT.insert (operator, "output", 0, high)
      end (*of exception case*)

      "alter"     :   begin   (*get operator request from SUPERVISOR
                                alter either directory or line status*)
                          SUPERVISOR.receivereq (opreq);
                          with opreq do
                          case key of
  "alter directory":   (*values give line# and new primary and alternate
                         destinations*)
                      begin with directory (value(1)) do
                             primary := value (2); alt1 := value (3);
                             alt2 := value (4) end
                      end;
```

Figure 5.19 (Continued)

Switch Process

```
"alter line status"  :  (*values give line# and new status*)
                        begin linestatus(value(1)):= value (2) end
                        end (*of case*)
     end (*of with*)
     end (*of alter case*)


     "preemption"     :  begin (*notify operator of pre-emption data
                                 is internal msgid*)
                        index := data
                        opout.data := names(index).msgid; (*external
                                                              name*)
                        opout.size.:=
                        SUPERVISOR.sendoutput (opout);
                        LINEOUTPUT.insert (operator, "output",
                                           0, low)

                        end (*of pre-emption case*)

          end (*of entire case statement*)

          end (*of loop*)
          end SWITCH;
```

5.9 Operator Group

The operator group consists of six components: input control process, output control process, SUBSCRIBER device module, SUPERVISOR module, RETRIEVE process, and old archive device module. The components are connected to each other as was shown in Figure 3.7. The switching node operator can send and receive messages in the same way as other subscribers. The operator can also make certain requests and receive control and exception output messages. Programs for each of the operator group components are presented in this section.

The operator is assumed to have an IO terminal which is identical with those for subscribers. Therefore the device interface in the operator group is a SUBSCRIBER device module identical to that in Figure 5.14.

The operatorinput control process is a slight modification of the SINPUT process of subscribers (Figure 5.12). The changes are shown in Figure 5.20; they result from the fact that the operator can generate two types of input: regular messages and operator requests. Regular messages are handled in a manner identical to that for subscribers. Operator requests are assumed to start with a distinguishing sequence of control characters. Their body consists of a key and up to four values. Once the start of an operator request is found (in the "find start" case), SINPUT's status is set to "find request." The request is then read

Figure 5.20

SINPUT Process for Operator

Make the following changes to SINPUT:

(1) use: add SUPERVISOR, operatorrequest to use list

(2) variables : add

```
        opreq : operatorrequest; (*kind and values of
                                    operatorrequest*)
```

(3) "find start" case:

```
    add a search for start of operator request sequence.
         of control characters

    if start operator request found
         then current := 0;
              status  := "find request" end;
```

(4) add "find request" case as follows:

```
    "find request" :
         begin  (*build operator request*)
              if current = 0 then opreq.key := ch;
                                  inc(current)
                             else opreq.value(current) := ch;
                                  inc(current)
                             end

         if end of request then
              case opreq.key of
         "status" : begin
                        NOTICE.post ("status", opreq.value (1))
                    end;

         "cancel" :  begin
                        NOTICE.post ("cancel", opreq.value (1))
                     end;
         "wait" :   begin
                        NOTICE.post ("wait", opreq.value (1))
                    end;
```

Figure 5.20 (Continued)

SINPUT Process for Operator

```
"restart" : begin
               NOTICE.post ("restart", opreq.value (1))
            end;

"alter" :   begin
               SUPERVISOR.sendreq (opreq);
               NOTICE.post ("alter", 0)
            end;

"new tape" : begin

          if opreq.value (1) = "active-archive"
             then ACTIVE-ARCHIVE.resume
             else OLD-ARCHIVE.newtape (opreq.value(1))
             end;

"retrieve" : begin
               SUPERVISOR.doretreive(opreq)
             end;
"cancel retrieve" : begin
               SUPERVISOR.cancelretrieve
             end
 end; (*of case statement*)
 status := "find start" (*find next operator request
                           or start of message*)

end; (*of find request case*)
```

and stored one character at a time. Once finished, a case statement on the key is executed. Status, cancel, wait, and restart requests post a NOTICE for SWITCH. Alter sends the request data to SUPERVISOR and then posts a NOTICE (there are more data values to pass than post can accept). New tape requests signal that a new archive tape has been mounted so the appropriate archive (ACTIVE or OLD) is called. The retrieve request causes a retrieve message to be sent to the RETRIEVE process (see below) via SUPERVISOR. Finally, a retrieve can be cancelled by the cancel request. After processing an operator request, SINPUT for the operator sets status to "find start" to look for the next input.

The SOUTPUT process for the operator is only slightly changed from SOUTPUT processes in subscriber groups (Figure 5.13). The changes are shown in Figure 5.21. Since the operator receives special output commands, the change is to add one more case to process the one more kind of LINEOUTPUT. The data for the operator comes from SUPERVISOR. It is merely written out by calling SUBSCRIBER.write.

The SUPERVISOR module (Figure 5.22) interfaces the operator's SINPUT and SOUTPUT processes to SWITCH and RETRIEVE. It defines seven operations: sendreq, receivereq, sendoutput, receiveoutput, doretrieve, getretrieve, and cancelretrieve. Sendreq and receivereq are used to send operator requests from SINPUT to SWITCH. Available requests are stored within SUPERVISOR in a requests queue. Sendoutput and receiveoutput are used to send operator output messages from SWITCH to

Figure 5.21

SOUTPUT Process for Operator

Make the following changes to SOUTPUT

(1) use - add SUPERVISOR, operatoroutput

(2) variables - add
```
                opout : operatoroutput
```

(3) add "output" case as follows:

```
"output" : begin
           (*fetch operator output data and write it out*)
           SUPERVISOR.receiveoutput (opout);
           i := 0;
           repeat
               SUBSCRIBER.write (opout.data[i])
           until  i = opout.size
           end
```

SOUTPUT. They too are stored within SUPERVISOR in a queue. Doretrieve and getretrieve are used to send retrieve requests from SINPUT to RETRIEVE and are also queued within SUPERVISOR. Cancelretrieve is called by SINPUT to cancel a retrieve. It sets a flag which is exported from SUPERVISOR and examined periodically by RETRIEVE. This flag (stopretrieve) serves the same role as did the pre-empt flags in LINEOUTPUT. The code for each of the seven SUPERVISOR operations is straightforward. Note that SUPERVISOR could be broken into three separate interface modules since the operations work in pairs. We did not do so, however, because it makes sense to group all the SUPERVISOR interface operations together. In this way, the entire interface between the operator and other processes appears in one place.

The RETRIEVE process (Figure 5.23) processes retrieve requests sent by the operator input controller via SUPERVISOR. There are three kinds of retrieves: copy, retransmit, and trace. The kind of request is indicated by opreq.value[1] which is used as a case statement selector. The copy retrieve causes all blocks of a message (identified by opreq.value [2]) to be read from an old archive tape and printed on the operator's terminal. The retrieved message is sent to the operator as if it were a new message. Namely, RETRIEVE builds a header, sends it to SWITCH via LINEINPUT, and then retrieves each message block and stores it on a MEMORY file. When the end of the retrieved message is found, SWITCH is notified.

The retransmit type of retrieve causes an archived

Figure 5.22

Supervisor Module

```
interface module SUPERVISOR;

     use operatorrequest, operatoroutput; (*data types*)

     define  sendreq, receivereq, sendoutput, receiveoutput,
             stopretrieve, doretrieve, get retrieve, cancelretrieve

     var requests : queue n of operatorrequest;
             requestavail, requests not full : signal;

             output : queue n of operatoroutput;
             output not full : signal;

             retrievals : queue n of operatorrequest;
             retrieval not full, retrieveavail : signal;

             stopretrieve : Boolean; (*signals RETRIEVE process to
                                       stop a retrieval*)

   procedure  sendreq (opreq : operatorrequest);
              begin  (*called by SINPUT*)

                   if requests.size = n then wait (requests not full) end;
                        requests.insert (opreq);
                        send (requestavail)

              end

     end sendreq;

  procedure   receivereq (opreq : operatorrequest);
              begin  (*called by SWITCH*)
                   if requests.empty then wait (requestavail) end;
                   opreq := requests.remove;
                   send (queue not full)
              end receivereq;

  procedure   sendoutput (opout : operatoroutput);
              begin (*called by SWITCH*)
                   if output.size = n then wait (outputnotfull) end;
                      output.insert (operatoroutput)
              end sendoutput;
```

Figure 5.22 (Continued)

Supervisor Module

```
procedure    receiveoutput (opout : operatoroutput);
         begin (*SOUTPUT knows message is available*)
              output.remove (operatoroutput);
              send (outputnotfull)

         end receiveoutput;

procedure    doretrieve (opreq : operatorrequest)
         begin (*called by SINPUT*)
              if retrievals.size = n then wait(retrievalnotfull)
                                                        end;
                  retrievals.insert  (opreq),
                  send (retrieveavail)

              end
         end doretrieve;

procedure    getretrieve (opreq : operatorrequest);
         begin (*called by RETRIEVE*)
              stopretrieve := false; (*it may have been on*)
              if retrievals.empty then wait (retrieveavail)
              retrievals.remove (opreq);
              send (retrievalnotfull)
         end getretrieve;

procedure    cancelretrieve; (*called by SINPUT*)
         begin stopretrieve := true
         end cancelretrieve;

begin   stopretrieve := false

end     SUPERVISOR;
```

message to be fetched and sent just as if it were a new message. The message is processed in the same way as for copy above except that the header used is the message's original header. For the retransmit case RETRIEVE acts exactly like an SINPUT process.

The final type of retrieval is the trace which causes all actions taken on a message to be printed on the operator's console. This is accomplished within RETRIEVE by building a header to direct a message to the operator, reading actions from OLD-ARCHIVE and storing each action as a block on MEMORY. The only difference between copy and trace is that the former retrieves the data in a message while the latter retrieves actions taken on a message.

To retrieve data or actions from archived messages, RETRIEVE calls the OLD-ARCHIVE device module (Figure 5.24). OLD-ARCHIVE defines three operations (retrieveaction, retrievedata, and newtape) and contains two driver processes (datatape and actiontape). Retrieveaction is called to retrieve the next action with a given id from the currently mounted action tape (a different action tape than the one being filled by ACTIVE-ARCHIVE). It does so by searching tape blocks for an actionmessage with the appropriate id. Once an action message is found it is returned. When retrieve action requires the next input block on the action tape, it signals the actiontape driver and waits. If the end of the action tape is reached, a notice is sent to SWITCH which in turn informs the operator. Once the operator

Figure 5.23

Retrieve Process

```
process RETRIEVE;

     use SUPERVISOR, stopretrieve, OLD-ARCHIVE, operatorrequest,
              operatoroutput, header, block, actionmessage, msgid, REPLY

     var      opreq : operatorrequest;
              opout : operatoroutput;
              hd :  header;
              bl : block;
              act : actionmessage;
              id : msgid; result : integer; cnt : integer;

     begin    loop (*main loop - once per retrieval*)
              SUPERVISOR.getretrieve (opreq);
                   (*in opreq, value[1] names the type of request to
                     perform - they are :  copy - print message on
                                                  operator's console
                                    retransmit - re-send message to
                                                  destination
                                        trace   - print all actions take
                                                  on message on operator
                                                  console
                         value [2] identifies the message to retrieve*)

              id := opreq.value [2];
              case opreq.value [1] of
"copy" :      begin (*copy entire message on operator's console*)
                   build new header in hd - treat retrieved message
                       as new input sent to operator;
                   put copy of header in bl;
                   LINEINPUT.sendhead (hd); REPLY.receive ("line#",
                   MEMORY.create (id,size);                    result);
                   MEMORY.write(id, bl);
              loop (*get body of message*)
                   OLD-ARCHIVE.retrievedata (id, bl);
                   MEMORY.write (id, bl); (*put block back on auxiliary
                                            memory*)
                   when end of msg in bl or stop retrieve do exit;
              end
                   (*once end is found signal SWITCH*)
                   NOTICE.post ("end", id)
     end (*of copy case*)
```

Figure 5.23 (Continued)

Retrieve Process

```
"retransmit" :  begin
                (*this case is like copy except actual header is
                  used to direct the output*)
                  OLD-ARCHIVE.retrievedata (id, bl);
                  transfer items from bl to hd;
                  LINEINPUT.sendhead (hd);
                  REPLY.receive ("line", result);
                  MEMORY.create (id, size);
                  MEMORY.write (id, bl);
                  loop
                       OLD-ARCHIVE.retrievedata (id, bl);
                       MEMORY.write (id, bl);
                       when end of msg is in bl or stop retrieve do
                                                              exit
                  end
                  NOTICE.post ("end", id)
        end (*of retransmit case*)

"trace" :       begin
                (*retrieve all actions taken on a message and print
                  them on the operator's console - build message out
                  of actions and route it as for normal messages*)
                  build header - destination is operator's console
                  LINEINPUT.sendhead (id);
                  REPLY.receive ("line", result);
                  MEMORY.create (id, size);
                  loop  (*retrieve actions*)
                       OLD-ARCHIVE.retrieveaction (id, act);
                       copy act into bl;
                       MEMORY.write (id, bl);
                       when last action on msg or stop retrieve do
                                                              exit
                  end
                  NOTICE.post ("end", id)
              end (*of trace case*)
         end  (*of main loop*)
end RETRIEVE;
```

has mounted a new action tape, he inputs a new tape command which causes the operator's SINPUT process to call OLD-ARCHIVE.newtape. This reinitializes OLD-ARCHIVE variables and causes the first tape block to be read. Once reading is complete, retrieveaction is signalled and proceeds as above.

With this scheme, the operator must maintain a catalogue indicating which messages are on which archive tapes. It is his responsibility to mount the appropriate tape before issuing a retrieve request. OLD-ARCHIVE merely reads from where he is on the currently mounted tape and informs the operator when the end of tape is reached. The operator must then mount the appropriate next tape.

The retrievedata operation is called by RETRIEVE to fetch the next message block with a given id from the currently mounted data tape. Its implementation is analogous to that for retrieveaction.

The two driver processes in OLD-ARCHIVE read the next record from the data and action tapes when signalled to do so. Their implementation is straightforward. The entire program for OLD-ARCHIVE follows as Figure 5.24.

5.10 System Initialization

The code for each process and module of the message switch system has now been described. All that remains to complete the switching node program is code to initialize the main processes. The initialization code is shown in Figure 5.25.

Figure 5.24

Old Archive Device

```
device module OLD-ARCHIVE;

     define    retrieveaction, retrievedata, newtape;

     use       block, actionmsg

     const     actiontapesize = m1;          (*same values*)
               datatapesize = m2;            (*as in ACTIVE-ARCHIVE*)
               actionrecordsize = n1;
               datarecordsize = n2;

     var       arnO, drnO, abnO, dbnO : integer;
                  (*current count of records and blocks*)
               actionbuffer : array 1 : actionrecordsize of
                              actionmsg; (*record from action tape*)
               databuffer : array 1  :  datarecordsize of record id :
                               integer; info : block end;
                               (*record from data tape*)
               inputaction, actiondone, inputdata, datadone : signal;

               actionavail, dataavail : Boolean;
               actionstatus, datastatus : integer;

               tapemounted : signal; (*end of tape synch.*)

procedure  retrieveaction (id : integer; var msg : actionmsg);
           (*retrieve next actionmsg with identifier id*)
     begin
     loop  (*loop until find action*)
             inc(abnO);
             while abno <= actionrecordsize do (*look at actions*)
                  when actionbuffer (abno).msgid = id (*got it*)
                       do msg := actionbuffer (abno);
                            result = "found it"
                       exit
                  inc(abno)
                  end;
```

Figure 5.24 (Continued)

Old Archive Device

```
            (*end of record so fetch next one if possible*)
            if arno = actiontapesize
                 then NOTICE.post ("exception", "end of action tape"
                      wait (tapemounted) end
            actionavail := true; signal (inputaction)
            wait (actiondone);
            inc (arno); abnO := 0 (*next record, first block*) .

        end (*of loop*)
    end retrieve action;

procedure  retrievedata (id : integer; var bl : block);
           (*retrieve next block with identifier id*)
    begin

    loop (*until find data*)

        inc(dbno)  (*look in current record*)
        while dbno <= datarecordsize do
            when databuffer (dbno).id = id
                 do bl := databuffer (dbno).info;
                    result := "found it" exit
            inc (dbno)
            end
        (*end of record so fetch next one if possible*)
        if drno = datatapesize
            then NOTICE.post ("exception", "end of data tape")
                 wait (tapemounted) end;
        dataavail := true; signal (inputdata);
        wait (datadone);
        inc(drno); dbno := 0; (*next record, first block*)

    end (*of loop*)
end retrievedata;
```

Figure 5.24 (Continued)

Old Archive Device

```
procedure   newtape (kind : integer);

     begin  (*initialize and get first record from new tape*)
         if kind = action
              then arno := 0; abno := 0;
                   actionavail := true; signal (inputaction);
                   wait (actiondone);
                   inc (arno)
              else drno := 0; dbno := 0;
                   dataavail := true; signal (inputdata);
                   wait (datadone);
                   inc (drno)
              end
         signal(tapemounted)
         end newtape

process  datatape;

     begin loop
         if not dataavail then wait (inputdata) end;
         initiate read into databuffer
         doIO
         if error then datastatus := "error"
                  else datastatus := 0 end;
         dataavail := false; signal (datadone)
         end
     end data tape;

process  actiontape;

     begin loop
         if not actionavail then wait (input action ) end;
         initiate read into action buffer; doIO;
         if error then actionstatus := "error"
                  else actionstatus := 0 end;
         actionavail := false; signal (actiondone)
         end
     end actiontape
```

Figure 5.24 (Continued)

Old Archive Device

```
    (*initialize device module*)

begin  arnO := 0; abnO := 0; drnO := 0; dbnO := 0;
       dataavail := false; actionavail := false;
       datatape ; actiontape

end OLD-ARCHIVE
```

Figure 5.25

System Initialization

```
begin  (*activate each main process*)

       for each subscriber group and the operator do
           SINPUT;
           SOUTPUT;

       SWITCH;
       RETRIEVE

end
```

6.0 Summary and Evaluation

The description of a representative message switching communications system and its implementation in Modula have now been completed. This chapter summarizes the presentation and discusses its relation to the design process. The utility of Modula as a design language is then evaluated.

6.1 Summary of Design Technique

The design presented here has been described in the same order in which it was developed. It evolved from a sequence of five steps. First,the basic system functions were identified and described (in Chapter 2). System functions in this case were specified by communications people who use message switching systems. My role at this stage, as the designer, was to discuss the functions with intended users so that we could both come to agreement on the purpose and scope of the proposed system and become comfortable with each other's vocabulary. In addition, it was (and generally is) helpful to lay out a typical hardware configuration in order to get a better feel for the size and nature of the system. The hardware need not be considered in detail at this point, however.

The second step was to specify in detail the formats of input and output messages. (This was also done in Chapter 2). System functions describe how information is processed; this step in the design describes what is processed. It completely

characterizes the user's view of the system.

The third step was to develop an organization, in terms of Modula constructs, for a system having the functions enumerated in step one. Modula has processes and modules as its basic building blocks for multiprogramming systems. Various organizations were considered at this stage, all in terms of how the functions could be realized using processes and modules. The organization settled on was shown in Figure 3.3. Refinements of the groups in Figure 3.3 were shown in Figures 3.4 - 3.8. The actual design proceeded in exactly this manner. First important groups of processes and modules were identified; in this case the groups implement IO interfaces and the central switching function. In general, a similar correspondence of groups to IO devices and major system functions should occur. Each group was in turn refined into modules and processes. Finally, the interconnection of groups, in this case the interface between IO groups and the SWITCH process, was organized in terms of modules.

The fourth step was to list the actions of each major system component. This was presented in Chapter 4. In the message switch there are four major components: input, switch, output,and the operator. The first three correspond to the phases which an individual message goes through as it is processed by the system. For each of these components, a path description of its actions was developed. Once this was complete, an ordered list of the actions taken in pro-

cessing each message was compiled. (Figure 4.4). At this point, the design was discussed in detail with the people who had contracted for the work. This allowed misconceptions and ambiguities about the system functions to be clarified. It helped me to be sure of the direction I was headed and helped the contractors to better understand the program they would be getting.

The fifth step was to actually program each component. No programming was done (or should never be done) until the organization and system actions were understood by myself, and agreed to by the contractor. Once the organization of the whole system is well understood, it becomes relatively easy to program each component. This is not to say that creativity is no longer needed though! Programming large components (e.g. MEMORY or even LINEOUTPUT) is still a rewarding challenge.

These five steps - system functions, IO interfaces, organization, component actions, and programming - were followed in order for the most part. The steps are not completely independent, however, so some iteration occurred. The program for MEMORY, for example, ended up differently than had been originally envisioned. This caused a change in the internal organization of the MEMORY group (step 3) and in the way in which it was accessed (step 5). Of importance though is the fact that the change to MEMORY did not affect any other aspect of the organization. The need for

and role of memory remained unchanged. The only external effect of the reorganization was a change in the syntax of statements which access the memory.

6.2 Evaluation of Modula

Overall, Modula proved to be an excellent tool for the design of the message switching system. In at least four respects, Modula made it easy to go from the specification to the implementation of the system.

First, the building blocks of Modula - processes and modules - were both appropriate and easy to use. The clarity and reliability of an implementation is obviously affected by the implementation language. In my opinion, Modula is the best existing language for multiprogramming systems. Interface modules provide exclusion of access to shared variables and make it easy to pass data as records. They make it easy to both describe process interfaces and reason about the effect of process interaction. And device modules provide a natural, encapsulated means for describing device interfaces. The power of the language very definitely increased my productivity and enabled me to program the entire system in about 15 days. Without access to a compiler, I have undoubtedly made numerous unintentional syntactic and logical errors. Having described this design and implementation to numerous people however, I am convinced that no major or global errors exist. To go from this report to a working system should only require debugging each individual

component. Some changes may be required in order to tune the system for good performance but most of these changes should occur only within device modules (e.g. changes to buffer sizes). It is obviously a guess, but I think that this system could be made operational in at most a very few months, given a compiler.

The second value of Modula is the power of device modules as a method for interfacing to IO devices. For one, device modules provide users with a natural, procedural interface to devices. For example, the subscriber control processes (SINPUT and SOUTPUT) input and output characters by calling read and write procedures. Details of buffer management, IO synchronization, and interrupts are hidden from the user. It was also possible to schedule future access to auxiliary memory (within AUXMEM) in parallel with disk access. In fact, interface and device modules made possible the clean separation of the file system functions in MEMORY (e.g. management, memory mapping, and deadlock prevention) from the device functions in AUXMEM (e.g. scheduling and buffer management). A final advantage of device modules is the ability to use different device access methods in SUBSCRIBERS and TRUNKS. The SUBSCRIBER modules used the doIO instruction because of the assumption that terminals give interrupts. The TRUNK modules on the other hand used timing signals to synchronize IO because of the assumption that trunk lines periodically provide or expect characters. Programming these differences is straightforward and they are

hidden from users of SUBSCRIBERS and TRUNKS.

A third feature of Modula, the ability to export read only variables from modules, made it easy to implement output pre-emption. The output control processes could test for pre-emption by merely checking a flag set by LINEOUTPUT. If this flag were not accessible outside of LINEOUTPUT, output controllers would have had to call a LINEOUTPUT procedure in order to interrogate the flag. In addition, note that changing the grain of pre-emption, namely the frequency at which the pre-empt flag is checked, merely involves moving the when statement in output controllers. Also note that LINEOUTPUT can easily restart pre-empted messages because they remain on a linequeue until completely processed.

The fourth and final positive aspect of Modula is its apparent efficiency. The amount of storage and execution time required by the Modula kernel (which implements processes, exclusion, signals, and IO completion) is minimal [10]. Most of the storage space and execution time used in the message switch should result from functions in the system itself.

In spite of its power, Modula is slightly deficient in three respects. First, because processes and modules cannot appear in type declarations, subscriber and trunk components must be declared for each terminal and trunk line. This leads to a tremendous expansion in the size of the program listing even though each subscriber group or each trunk group

is the same. Obviously, the same storage space is required in either case so efficiency is not affected. Readability and clarity is, however. Along the same line, the systems as defined requires a very large number of processes - four for each subscriber and trunk group. Since a typical system has approximately 50 local subscribers and 3 remote trunk lines, this results in over 200 processes. How this could affect efficiency is unknown.

A second, although minor, deficiency of Modula is the lack of queues or a way to construct them easily. As pointed out in the previous chapter, a queue can be implemented by a module. But a separate module is required for each different type of queue. It would be nice to have generic (polymorphic) procedures which operate on any type of queue. In parallel systems, queueing occurs frequently within interface modules so a general queueing facility, or the tools with which to construct one, would be quite useful.

The final deficiency of Modula as a language for designing fairly large systems is the <u>use</u> phrase. In Modula, <u>use</u> is optional; if omitted a module has access to all globally defined objects not renamed in the module. At a minimum, however, <u>use</u> should be required. A module should explicitly state what it is using so that a compiler can catch invalid accesses. Better yet, <u>use</u> should be replaced by a <u>grant</u> statement which specifies, when a process or module is declared, which other objects can access it. At present, Modula

puts access control in the hands of the user of an object; it should instead be put in the hands of the object's declarer in order to insure that the object is adequately controlled. This distinction has little effect in a small system but in a large system, especially one implemented by many people, it can have a great effect upon reliability. When one object is changed, it should be clear, and explicitly stated in the program, which other objects are affected by the change.

The above three deficiencies of Modula can and should be removed in a language for general system programming such as that proposed for the Department of Defense. They are relatively minor, however, and should not obscure the fact that Modula is the most powerful tool currently available for the design and construction of structured multiprogramming systems. The message switching system in this report is but one example of Modula's utility.

Acknowledgement

Sera Amoroso and Derek Morris conceived of this project and served as sounding boards for the design as it was developed. Their assistance is greatly appreciated.

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